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# H.F. Hauff Pruner - Power System

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Senior Project

# H.F. Hauff Pruner

Power System



Tom Wilson

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## Contents

Introduction: .....	5
Motivation .....	5
Function Statement .....	5
Requirements .....	5
Engineering Merit .....	6
Scope of Effort .....	7
Success Criteria .....	7
Design and Analysis .....	7
Approach: Proposed Solution .....	7
Design Description .....	7
Benchmark .....	8
Performance Predictions .....	9
Description of Analyses .....	9
Scope of Testing and Evaluation .....	10
Analysis .....	10
Approach: Proposed Sequence .....	12
Device Shape: .....	12
Device Assembly, Attachments .....	12
Tolerances, Kinematic, Ergonomic, etc .....	12
Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits .....	13
Methods and Construction .....	13
Construction .....	13
Description .....	13
Drawing Tree, Drawing ID's .....	14
Parts list and labels .....	14
Manufacturing issues .....	14
Testing Method .....	16
Introduction .....	16
Method/Approach .....	16
Testing Procedures .....	16
Deliverables: .....	17
Budget/Schedule/Project Management .....	17
Proposed Budget .....	17
Proposed Schedule .....	17

Project Management .....	18
Discussion.....	19
Design Evolution/Performance Creep .....	19
Project Risk Analysis.....	19
Successful .....	19
Next Phase .....	19
Conclusion .....	20
Appendix A – Analyses .....	21
A1: Design Concept.....	21
A2: Trigger Concept.....	21
A3: Trigger Circuit Drawing .....	22
A4: Duty Cycle Calculation .....	22
A5: Mechanical Power Output .....	23
A6: Test Blade Assembly (Testing Round #1).....	23
A7: Cutting Test Data (Testing Round #1) .....	24
A8: Tree Branch Testing (Round #2) Testing Apparatus.....	28
A9: Tree Branch Testing (Round #2) Data .....	29
A10: Maximum Required Force Blade Orientation Calculation.....	32
A11: Average Cutting Point Force Calculation.....	33
A12: Actuator Pin Sizing Calculation .....	34
A13: Aluminum vs. Carbon Fiber Driving Rod .....	35
A14: Carbon Fiber Driving Rod Tension Sizing.....	36
A15: Collar Stress Concentration Calculation.....	37
A16: Driving Rod Linkage Width Sizing.....	38
.....	38
A17: Driving Rod Buckling Analysis .....	39
39	
A18: Cutting Point Force Calculation .....	40
.....	40
A19: Shear Pin Sizing for Cutting System Pin.....	41
.....	41
A20: Surplus Center Linear Actuator Dimensional Drawing ... <b>Error! Bookmark not defined.</b>	
Appendix B – Power System Drawings .....	42
B1: Drawing A1 – Power Transmission Assembly.....	42
B2: Drawing A2: Actuator Assembly .....	42
B3: Drawing A3: Driving Rod Assembly .....	43
B4: Drawing A4: Actuator Model .....	44

B5: Drawing A5: Insert - Actuator to Driving Rod.....	45
B6: Drawing A8: Driving Rod .....	46
B7: Drawing A9: Insert – Actuator to Blade Linkage.....	47
B15: Hauff Pruner Drawing Tree .....	54
Appendix C – Parts List.....	55
C1: Parts and Price List .....	55
Appendix D – Budget .....	55
Appendix E – Schedule .....	55
E1: Gantt chart: Project Schedule.....	56
Appendix F – Expertise and Resources.....	57
Appendix G – Testing Data .....	57
Appendix H – Evaluation Sheet .....	57
Appendix I – Testing Report .....	57
Appendix J – Resume .....	1
Appendix K – References.....	2
Appendix L – Acknowledgements .....	2

## Introduction:

### Motivation

Founded in 1947, H.F. Hauff Company Inc. of Yakima, Washington has been a nation-wide manufacturer and distributor of specialized agricultural equipment. The company is constantly striving to provide quality, dependable products using innovative technological advancements and the highest engineering standards. The company's president, Neil Hauff, is the driver behind this innovation. Neil's efforts towards perfection and customer satisfaction are the motivation behind this project.

Neil Hauff was approached by a Greek organic orchardist, Emmanuel Maniadakis. Emmanuel approached Neil with his Treelion D45-900 battery-powered pruner and he explained the issues he has with the current design.

After operating for a long time, the linear actuator which provides cutting force becomes too hot for the operator to hold the housing surrounding the actuator, even when wearing gloves. The current reach of the pruner is also not sufficient. The single-finger trigger is difficult to operate when wearing gloves and causes discomfort on the operator's finger after pruning for a long time. Emmanuel would prefer a 4 finger trigger (hand trigger) similar to the triggers found on pneumatic tools. With the current pruner, a cut is made by holding down the trigger until a cut is made and then letting go of the trigger. Emmanuel needs a cut to be made by only pressing the trigger once, momentarily.

The new design will eliminate the heat issue with the current pruner actuator and housing. The new design will also have a longer reach. The single-finger trigger system will be replaced with a new trigger system that is more comfortable for the operator and easier to operate with gloves. For the new design, a cut will be made by pressing the trigger once, momentarily. However, Emmanuel is satisfied with the current power supply system, a 44 V DC battery belt.

### Function Statement

Function statement #1 applies to the new pruner design in its entirety. Function statement #2 applies to the Power system of the new pruner design.

#### **1. H.F. Hauff Pruner (Entire Pruner):**

- A device is needed which can cut branches all day without overheating.

#### **2. H.F. Hauff Pruner: Power System:**

- A device is needed that transmits cutting force to the pruner blade, when initiated by the operator.

### Requirements

The bulleted list below contains the design requirements for the Hauff Pruner in its entirety.

- The distance from the trigger to the end of the pruner blade must be no shorter than 36"
- After operating at a pruning rate of 250 1" diameter branches/ hour for 6 hours, all the pruner components must remain under 110° F.
- The pruner must be able to cut at least a 1.5" diameter branch.

- The trigger system must be a four-finger hand trigger. (as per customer)
- The power supply must be a 44V DC battery belt. (as per customer)
- The combined weight of the pruner must be no greater than 15 lbs.
- The pruner center of mass must be within the first quarter of total pruner length (starting from handle end)
- The total cost to manufacture the pruner can be no greater than \$2,500.
- The cut cycle time of each pruner cut can be no longer than 2s. (as per customer)
- At any point on the pruner, the width can be no greater than 6 in.
- The cutting cycle must be initiated by a single, momentary pull of the trigger, performed by the operator. (as per customer)
- The pruner must be manufactured within a 9 week period.

The bulleted list below contains the design requirements for the Hauff Pruner power system.

- The power system must use a 44 V DC power supply (as per customer)
- The power system must be able to supply a force to the pruner blade which can cut at minimum a 1.5" diameter branch.
- The weight of all power system components must be no greater than 7 lbs.
- The power system components must be able to fit inside 2" inner-diameter housing.
- At least 50% of the power system components' weight must be positioned directly over the trigger system for ergonomic balance.
- When the power system is operating at a pruning rate of 250-1" diameter branches/ hour, the components must not exceed a temperature of 110 degrees F.
- The pruner power system must provide at least 450 lbs. of force to the pruner blade.
- The cutting power system must supply cutting force for 6 hours when pruning at a rate of 300 1" diameter branches/ hour.
- After a cut is initiated by the operator, the cut cycle must be no longer than 2.0 seconds. (as per customer)
- The cut cycle must be initiated by a single, momentary pull of the trigger. (as per customer)
- The trigger must be designed so 4 fingers are used to operate it. (Hand trigger) (as per customer)
- The cost of all power system components must be no greater than \$800.

## Engineering Merit

It is most important that the new pruner design is ergonomic. This is going to be achieved through overall weight, balance (weight kept near the handle), and a re-designed trigger system. However, the new design must also adhere to the design requirements regarding power capability, operating temperature, and reach of the pruner. A formula that will be used to find a better cutting force mechanism is the equation for duty cycle rating,  $D.C. = (T_c / T_o) * 100$ , where  $T_c$  = Time of cycle and  $T_o$  = time in between cycles. Finding the required duty cycle rating for the cutting force mechanism will help ensure the new power system doesn't overheat during operation.

Engineering merit is also present in the use of Stress equations:  $\sigma = \text{Force}/\text{Area}$ . These calculations for average shear and tensile stress in the power system components help establish dimensions and material which are optimal. Material selection must be appropriate for each component in order to meet requirements and to keep cost down. Engineering merit can also be found in the material

### Scope of Effort

The main focus for the design of the Hauff pruner power system is its ability to provide necessary cutting force, cut cycle time, and consecutive cuts while maintaining a low operating temperature. The scope of effort also extends to the trigger system which must be a 4 finger hand trigger for ergonomic purposes.

### Success Criteria

The success of the pruner power system depends on its ability to; remain below 110 degrees F when operating at a pruning rate of 250 1"-diameter branches/hour and provide sufficient cutting force to the blade to cut a 1.5" diameter branch at minimum. However the success criteria of the pruner power system can also be defined by the following equation which incorporates all sections of the pruner design.

$$\text{Success Level} = \frac{(t)*(T)*(P)*(36 \text{ in. Length})}{1.5 \text{ in. Branch Diameter}}$$

"t" represents the time in seconds it takes for the pruner to complete one cut cycle. "T" represents the temperature of the housing surrounding the actuator/motor system after the maximum branch cut, 1.50 in. or the temperature of the housing after the pruner has cut 250 1 in. diameter branches in one hour. The 36 in. length refers to the required length from the trigger to the end of the blade. "P" refers to the maximum load required to cut a branch. The equation incorporates design requirements. If P is greater than 600 lb., T is greater than 110°F, or t is greater than 2.0 seconds, the success level will exceed a level of 146 s-°F-lb. Once this value has been exceeded, the pruner is not considered successful.

## Design and Analysis

### Approach: Proposed Solution

As stated before, the main problem with the power system of the current pruner is the operating temperature. The linear actuator and housing surrounding the linear actuator become too hot for the operator's hands. To fix this problem, the new pruner design must have a linear actuator which will not exceed a temperature of 110 degrees F when operating at a rate of 250 1" diameter branches/ hour for 6 hours. The selection of a more appropriate linear actuator is crucial to the success of the new design.

In order for the cutting cycle to be initiated by a single push of the trigger, electrical switches must be positioned inside the housing to open the circuit and reverse the motion of the actuator. (See **Figure 2-2**)

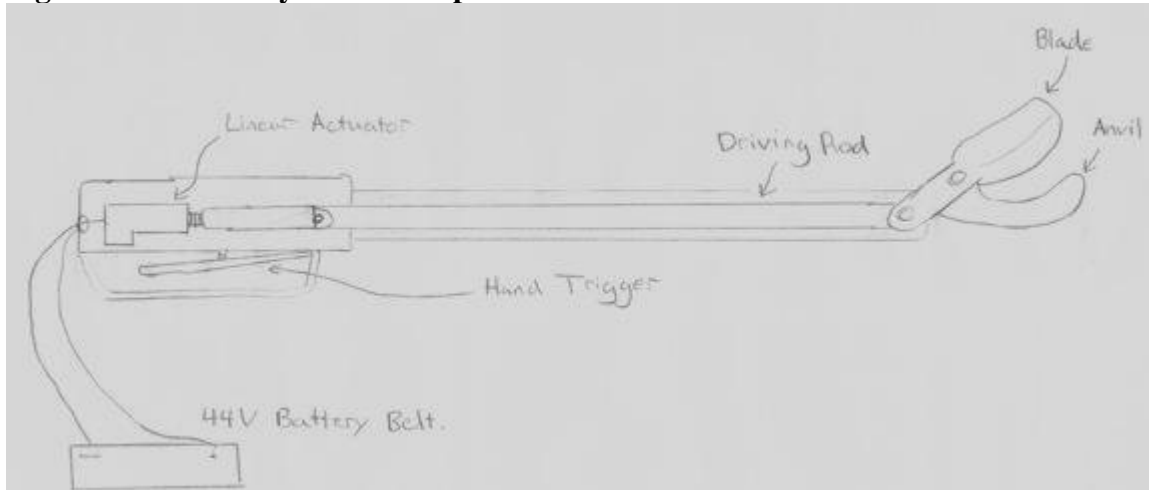
### Design Description

**Figure 2-1(Also found in Appendix A1)** below displays the basic components of the pruner power system in a conceptual sketch. The power supply is the 44 V battery belt. The linear actuator transmits cutting force to the blade through the linear motion of the driving



rod. The linear actuator will retract to close the blade and move forward to open it. The cutting motion is initiated by the hand trigger. The circuitry required for the cutting cycle (i.e. limit switches) is not displayed in this sketch.

**Figure 2-1: Power System Concept Sketch**



The cutting cycle must be initiated by a single pull of the hand trigger. The blade of the pruner is open when the actuator is fully forward. When the actuator is at this position, the power circuit is open due to a switch. The single push of the hand trigger will close this circuit and retract the actuator, closing the blade. When actuator reaches the end of the retraction stroke, the polarity must be switched which will send the actuator back in a forward motion until the circuit is opened again. **Appendix, A2** displays a conceptual sketch of the circuit switches.

In order for cutting cycle to be initiated with a single, momentary pull of the trigger, the circuit shown in **Figure 2-3 (Also found in Appendix, A3)** must be used. This circuit includes a N.C. (Normally Closed) switch, the trigger momentary switch, and a latching 3.P.D.T. (3 pole, double throw) switch. In the final design, a safety switch will also be included to ensure the cutting action can't be initiated by accident. And finally, the trigger circuit will also need a function to back out of a cut.

### Benchmark

The benchmark for the design of the pruner power system is the current power system found in Emmanuel's Treelion D45-900 electric pruner. **Figure 2-4** shows a picture of the Treelion pruner. This pruner is manufactured by Pellenc, a French agricultural company, and it costs \$1950 USD. **Figure 2-5** shows the linear actuator and linkage to driving rod found in the D45-900. The actuator is also manufactured, in-house, by Pellenc (Model #: 69068-E).

**Figure 2-4: Treelion D45-900 Pruner**



**Figure 2-5: Linear Actuator and Driving Linkage (D45-900)**



This is a very valuable benchmark for the design process because the customer was mostly satisfied with the Treelion's performance, aside from a few factors; overheating, ergonomics, and reach. Each member of the design team will use this benchmark as a guide for designing the optimized Hauff pruner.

### Performance Predictions

The linear actuator of the new pruner design will have an average surface temperature of 70 degrees F after pruning 250 1"-diameter branches in one hour. After going at this rate for six hours, the average surface temperature of the actuator will be 75 degrees. The actuator will be able to dissipate heat at a rate appropriate for the operation demands.

A single cut cycle will be sufficient to cut a 1.5" diameter branch. The pruner blade won't have to be backed out of the cut.

At a rate of 250 1"-diameter branches/hour, the new pruner power system will provide cutting force to the blades for 6 hours.

### Description of Analyses

First, an analysis will be performed to determine the appropriate duty cycle rating for the new design's linear actuator. Selecting an actuator with a suitable duty cycle rating is important because this will ensure that the new pruner design will not overheat when under the expected operating conditions. The duty cycle rating is a required specification for the selection of a more appropriate actuator. **Appendix A-5** shows the calculation for the duty cycle rating of the linear actuator.

Then, an analysis will be performed to determine the maximum linear force that is required from the actuator. The moment at which the most linear force is required for cutting a 1.5" diameter branch will be analyzed statically. The static analysis will take into account the geometry and angles in the blade linkage and blade. From this, the maximum linear force needed will be determined. This is a design parameter for the selection of a more appropriate actuator.

After the maximum required linear force is determined and an appropriate actuator is selected, an analysis on the actuator will be performed. This analysis is to determine the

maximum current that will be present in the circuit when the actuator is delivering force to the blade during the 1.5”diameter branch cut. This is a design parameter for the selection of circuit components.

### Scope of Testing and Evaluation

In order to test the new pruner design, a location with fruit trees must be used. During the pruner testing, a thermocouple must be used to observe the temperature of the pruner housing and linear actuator. During this testing phase, it must also be observed how efficient the cutting cycle is, with regard to battery life.

### Analysis

Listed below are the different methods of analysis which are used to design the optimized pruner.

#### Tree Branch Testing: Round 1

To establish how much force is needed to cut various sizes of branches and where, during the cut, the most force is required, a test was performed using the Tinius Olsen tensile tester. **Appendix A6** shows the testing device assembly that was manufactured for the first round of testing. **Appendix A7** shows the force vs. distance of travel through the branch. The main problem with this test was the simulated cutting action. The blade was brought directly down on the branch by the tensile tester, resulting in more crushing than cutting. This also resulted in a very high maximum cutting force, about 4,000 lb. (**Appendix A7**). In order to more accurately simulate the shearing action of the pruner blade/anvil better, a guillotine style cutting action will have to be utilized.

#### Tree Branch Testing: Round 2

The second round of testing resulted in a much more accurate value for required cutting force. **Appendix A8** shows a picture of the apparatus used for the second round of testing. The blade and anvil were taken from a pair of 32-inch Fiskars bypass loppers. The blade and anvil used on Fiskars were highly praised by the customer for their effectiveness. Therefore, the Fiskars blade and anvil geometry have been adopted into our design. The test data determined the force that was required at the end of the 2.50 inch moment arm, 500 lb., to cut a 1.50 inch branch. The test data for the Testing: Round 2 is found in **Appendix A9**.

#### Blade Orientation during Cut:

The geometry of the blade/anvil in Testing: Round 2 is known. Also, it is known how fast the Tinius Olsen tensile test was moving downward, 4.5 in/s. This linear, downward velocity was then converted to (in/s), 0.075 in/s. It is determined from the test data that, during the cut of 1.50 inch-diameter Cherry branch, that the maximum cutting force was needed when the Tinius Olsen had moved 1.8 inches from the start of the cut. The calculation in **Appendix A10** shows how it was determined that the maximum force during this cut was needed 24 seconds into the cut. After this value was determined, the video footage of the 1.50 in Cherry branch cut was reviewed. After 24 seconds into the test cut, the video was paused and the blade orientation during maximum required cutting force was documented. (See **Appendix A10**)

#### Average Cutting Point Force:

After the Fiskars blade/anvil orientation during maximum required force on a 1.50 inch diameter branch was determined, the approximate cutting point of the blade could be located from the visual analysis of the blade/anvil orientation. From this visual analysis, it was determined that the average cutting point on the Fiskars blade during maximum required force was 1.50 inches away from the pivoting cutting joint. Also the distance from the applied force to the cutting joint was observed to be 2.3125 inches. Now that the perpendicular distances were known, it could be determined that the reaction of the branch on the blade during this maximum force moment is 770.83 lb. (See **Appendix A11**)

#### **Duty Cycle:**

Establishing an appropriate duty cycle for the cutting force device is a helpful and practical parameter for selecting a more appropriate linear actuator for power delivery to the pruner blade. (If that is the best option for the cutting force device) **Appendix A5** shows a calculation which establishes a duty cycle value for the pruner cutting force device. It is assumed that the time between cutting cycles would be an average of 8 seconds. Therefore, if a linear actuator is to be used, it must have a duty cycle rating of 20% or greater.

#### **Mechanical Power Output:**

Even though a required linear force is not yet determined, the method that is used to find the required mechanical power output is shown on **Appendix A6**. If the required linear force is assumed to be 450 lbs., then the required power output is determined to be 50.9 Watts.

#### **Clevis Pin Sizing:**

**Appendix A12** shows the analysis that was performed in order to determine the minimum diameter of the clevis pin which is to be used to transfer force from the linkages to actuator connection. From the analysis, it is determined that minimum diameter the AISI 1020 pin should be to withstand maximum cutting force is 0.152 inches. Therefore, the pins that will be used in the assembly are 1/4" in diameter.

#### **Sizing the Carbon Fiber Driving Rod for Tensile Strength:**

**Appendix A13** shows the calculation which determines the required wall thickness of the aluminum or carbon fiber tube which will be used as the driving rod in the assembly. From the calculation, it is determined that the wall thickness of a carbon fiber tube must be at least 0.0073 inches to withstand the cutting tensile force, 600 lbs. It is also determined that an aluminum tube must have a wall thickness of 0.1495 inches in order to withstand the tensile force.

#### **Sizing the Width of the Driving Rod Linkage Width:**

**Appendix A16** shows the calculation that was done to determine the required width for the driving rod linkage (Drawing #12, **Appendix B12**). The thickness of the linkage 0.138" is a fixed dimensions to ensure the driving rod assembly still fits inside the housing. The size of the pin holes in the linkage are also fixed because it was determined that 0.25" was an appropriate diameter of the power system clevis pins. (See calculation in **Appendix A12**). It is determined that the width of the driving rod linkage must be at least 0.738" when made out of SAE 1020 Cold-drawn steel. Therefore, the final design width dimension of the linkage is 3/4".

#### **Driving Rod Buckling Analysis:**

**Appendix A17** show the calculation which determines that the dimensions established for the driving rod in tension (calculation in **Appendix A13**) still give the driving rod a

buckling load of 2,461 lb. This value is much higher than the rod would ever experience with maximum compressive load it receives from the actuator. Therefore, the rod would not buckle if the blade were to become stuck and could not open.

### **Approach: Proposed Sequence**

The numbered list below explains the proposed sequence of analyses for pruner power system.

1. The Tinius Olsen tensile tester will be used to determine the maximum force required during the cut of a 1.5" diameter branch. This test will also establish the point of the cut where the most force is required.
2. After the force required at the branch is determined, the department responsible for manufacturing the blades (Daniel Gibson) will perform a static analysis of the blade geometry during this point of the cut. From the analysis, it will be determined how much linear force is needed from the actuator.
3. After the required maximum linear force is established, this value and other parameters will be used to select a more appropriate actuator. The other specifications which will be considered are; stroke length, linear stroke velocity, amperage and power draw, duty cycle rating (See **Appendix A4**), maximum push/pull force, power supply voltage, and geometric dimensions.
4. After the appropriate actuator is selected, appropriate circuit components will also be selected which can handle the amperage of actuator operation.
5. Finally, the driving rod material will be selected with the following specifications in mind; weight, material tensile strength (cutting action puts driving rod in tension

### **Device Shape:**

The customer, Emmanuel Maniadakis, requested that the trigger system be a hand trigger. He wants the trigger for the pruner design to be similar to the triggers found on pneumatic hand tools. He has also requested that the pruner be at least 3 feet long (from trigger to blade end).

### **Device Assembly, Attachments**

The Makita XDT08 has been chosen as the most appropriate impact driver motor for the team's application and here's why:

- The brushless DC motor offers unparalleled efficiency and low maintenance in comparison to other brushed DC motors.
- The XDT08 is capable of producing 1420 in\*lb of torque under normal operation. This is sufficient for the team's application
- The XDT08 is capable of running at 2500 RPM under normal operation. This is a sufficient rotational speed in order to achieve the desired cycle time.
- The XDT08 weighs only 2 pounds. This is an ideal weight for the motor system.

### **Tolerances, Kinematic, Ergonomic, etc.**

All components of the optimized pruner power system, excluding the purchased actuator, contain tolerances on all dimensions. In compliance with A.N.S.I. Y14.5-2009 drawing standards, a documented Solidworks drawing of each power system component has been constructed (See **Appendix B**). In these drawings, dimensions containing decimal values with 2 decimal places have a tolerance of  $\pm 0.030$  inches. Drawing dimensions containing

decimal values with 3 decimal places have a tolerance of  $\pm 0.005$  inches. Tolerance stacking is a potential issue regarding the dimensions of the driving rod linkage and the connecting pins. Stacked tolerances for these components could cause the actuator shaft to become misaligned with the driving rod when it is rigidly housed.

The linear actuator for the optimized design produces a linear force, resulting in motion. Therefore, the kinematics of the actuator shaft motion must be discussed. In order to reach the optimal cycle time, the actuator must have linear velocity of 0.75 in/s during operation. The actuator retracts when providing cutting force. During the retraction, the actuator experiences the highest force in tension. When the actuator extends and returns the blade to the open position, the actuator is pulling, causing the power system components to be in compression.

Ergonomics is one of the most important factors for the pruner design. In order to comply with ergonomic standards for the design, multiple features are included. The trigger system must be a four-finger hand trigger to decrease the strain that a single-finger trigger places on the index finger of the operator. Also, the center of mass must be considered in the construction to reduce operator strain. One of the design requirements for the entire pruner is to keep the center of mass within the first quarter of the total pruner length.

## Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits

The optimized pruner power system design uses a safety factor of 2 for establishing the diameter of the pins used to transmit power. The calculation in **Appendix A12** shows how this safety factor was used to establish this design parameter. The required pin diameter for safe power transmission in the pruner has been established to be  $\frac{1}{4}$ ".

## Methods and Construction

### Construction

The power system of the pruner will now be entirely manufactured and assembled in the Hogue machine shop. The ball screw must be modified for the application. The ball nut guide will be a rapid prototype part. The hex adapter will be turned, drilled, and bored on the lathe. The aluminum thrust plates which surround the needle thrust bearing will be laser-cut in the Hogue facilities. The aluminum plate which screws to the ball nut will be manufactured with the Bridgeport milling machine. The driving rod is now welded to the aluminum plate on the ball nut. And finally, the aluminum pin which connects to the blade linkage will be first manufactured using the lathe and the milling machine.

### Description

The most recent design of the pruner power system is made up of a Makita Impact Driver (Model #: XDT08) (**See Appendix B5**), an hex adapter (**See Appendix A9**) which adapts the hex drive system at the end of the Makita into a torque transmitter for a ball lead screw (**See Appendix A6**). The ball screw drives a ball nut (**See Appendix A10**) forwards and backwards in a linear motion in the ball nut guide (**See Appendix A14**). An aluminum weld plate (**See Appendix A11**) is now attached to the ball nut through tapped holes added through the ball nut modification process. This weld plate is attached to the ball nut through fasteners to enable the aluminum driving rod (**See Appendix A12**) to be welded to



the top of the ball nut assembly. The linkage pin connector (**See Appendix A13**) is has an interference-adhesive fit with opposite end of the driving rod which is used to connect to the linkage of the cutting system. In order to keep thrust forces away from the motor and place them in the central housing tube, a thrust bearing (**See Appendix A8**) and two aluminum thrust plates (**See Appendix A7**) are press fit into the central housing tube to capture the thrust load created by the ball screw.

### Drawing Tree, Drawing ID's

**Appendix B15** displays the Drawing tree of the Hauff Pruner Components. All component which lead with the letter “A” in their drawing designation are components pertaining to the Power system of the pruner design.

### Parts list and labels

**Appendix C1** contains the parts list for the Hauff pruner components. Included in the parts list is quantity and price of each pruner component which will have to be purchased. The parts which are required to be purchased are a ball screw and ball nut from McMaster-Carr. Aluminum round stock, plate, and round tube from OnlineMetals.com And finally, the Makita Impact Driver, Dual 5 Ah batteries, and Makita dual-port charging pad will have to be purchased from Home Depot.

### Manufacturing issues

Many manufacturing issues have come to the attention of the pruner team as we have moved forward. During the second meeting with the customer for our fall quarter manufacturing meeting, it was determined that the current pruner design was entirely impractical and heavy. The customer set the pruner team on a redesign track. This is problematic for the manufacturing process because it has placed an intense time constraint on the project. However, with the manufacturing process being completed a little each week, it should be able to be finished by the end of winter quarter.

After the weight problem was addressed with a first round of re-designing, the problem of required linear force was addressed by optimizing the cutting system of the pruner in order to achieve the maximum mechanical advantage necessary during the maximum branch cut.

However, after the pruner had been optimized for mechanical advantage the H.F. Hauff sales department determined that the look of the optimized pruner was not very marketable. This resulted in another round of redesigning where the team has been dialing back the mechanical optimization in order to achieve a more consumer friendly look to the product.

Another manufacturing issue for the pruner team has been delivery times for necessary components. Many required components for the manufacturing process are taking much longer to arrive than we had previously thought they would. This has been an issue because many measurements and technical aspects of these components need to be researched in order to move the manufacturing process forward.

Now that the Redesign process had completed, the pruner team could move forward with manufacturing in Week 8 of Winter quarter. The following issues listed below became apparent as the manufacturing process moved forward.

- When manufacturing the aluminum driving rod, it was decided that the aluminum ball nut adapter which matched the 15/16-16 female threads on the ball nut would

be welded on to the aluminum driving rod. Due to unforeseen expansion and stresses introduced through welding, the driving rod seems not to share the same line of action as the ball screw. This has caused excess friction in the power system.

- The runout cause by the driving rod made it where the aluminum thrust plates which are used to be another source of excess friction within the system. Even with the clearance between the ball screw and the trust plates, the ball screw still rubs on the ID of the plates.
- The initial troubleshooting testing of the pruner brought another issue to the team. The team did not account for the bending that would occur in the blade housing when the blade and anvil separated during a large cut. After cutting the 4<sup>th</sup> 3/4" branch for testing, the blade housing bent sideways and support material had to be welded on to the housing.
- Due to time constraints, the team was not able to manufacture the Makita housing halves out of aluminum on the CNC mill. However, the pieces were made through a rapid prototype process. The analysis of the new housing material is still being completed. However, for the initial troubleshooting testing the housing halves did not seem to deform, deflect, or crack during operation. During spring quarter, the aluminum housing halves are going to be manufactured with aluminum on the CNC mill at the Hogue machine shop.
- Since the thrust plates caused excess friction within the power system, the ID and OD of the thrust plates was filed down to allow for an easier fit and allowance for runout.
- The screws which fasten the front housing of the Makita unit were originally going to be removed to allow longer #8-18 screws to be inserted from the front of the Makita housing which would hold the Makita in line with the action of pruner. However it was not considered that front housing for the Makita unit would still need to be firmly bolted down and the long screws would not accomplish this. To fix this, the team only used 2 of the long screw to hold to pruner in line. The other two screws kept the front Makita unit housing fastened down on the unit.
- The ball nut guide pieces were installed inside the tube using an EX 375 epoxy. However, the surface finish of the inside of the tube was not appropriate for the epoxy to get inside the surface imperfections. The guides eventually fell out. To fix this the inside of the tube was honed out using a honing kit and a DP 420 resin was used to adhere the guides inside the tube instead of the previously used epoxy. This solved the problem and the resin has worked well.
- Initially there were two ball nut guide pieces on opposing sides of the ball nut. However due to runout and line-of-action issues in the other parts of the pruner power system, only one could be used. Only using one of the guides greatly reduces friction inside the pruner and the function of the ball nut guides was still accomplished.
- The tolerances of the 3D printed material were not considered in the design of the ball nut guides. When printed and cooled, the ball nut guide pieces were .015 wider than they were specified in the design process. This caused a fit which was too tight inside the pruner. In order to achieve a more appropriate sliding-clearance fit in the ball nut guides, the flat face which mates with the ball nut had to be filed down accordingly.
- Since the trust plates were filed down to allow for the runout and line-of-action problems inside the pruner, they did not capture all the thrust on the ball nut. This caused the 7/16" hex nut driver which was installed on the back of the ball nut to become stuck inside the mounting head of the Makita unit. This issue is still being researched and solved.



- Now that thrust plates did not capture the intended amount of thrust in the ball screw, the 7/16" nut driver which was mated with the male 7/16" hex on the ball screw would not stay in. When the screw would experience a thrust load during operation it would slip out of the nut driver. To fix this, a hole was drilled on opposing sides of the nut driver and a spot weld was placed in the hole to keep the nut driver attached.

## Testing Method

### Introduction

The Power system of the pruner must be tested thoroughly to ensure that the customer, Mr. Maniadakis, is satisfied with performance and design. The testing of the power system will be focused around two factors; the system's ability to cut a 1.5" branch (**maximum branch cutting**), and the system's ability to cut at rate of 250 1 inch diameter branches per hour without exceeding an operating temperature of 110° F (**endurance branch cutting**).

However, this maximum operating temperature which was established in the requirements for the power system has changed as the design process has moved forward. The housing department (Erich Heilman) has made a design decision to have the motor of the linear actuator be placed behind the operator's hand. This placement of the actuator is different from the system found in the Treelion where the actuator was positioned directly under the operator's hand. The excessive heat caused Mr. Maniadakis discomfort and was a primary problem with the Treelion design. Since the 110° F operating temperature was established for the comfort of the user, it may be acceptable for the linear actuator to exceed the maximum temperature due to the position of the actuator motor in the new design.

### Method/Approach

The testing of the pruner power system is focused around two aspects of power system performance; maximum branch diameter cutting and endurance branch cutting. The materials which will be needed are listed below;

Testing Materials:

1. Thermocouple
2. Stopwatch
3. Spreadsheet Software (Microsoft Excel)

Both of the tests which will be performed for the pruner power system can be performed in the senior project room of Hogue Technology building at Central Washington University.

### Testing Procedures

1. Maximum Branch Cutting:

To ensure the power system is able to transmit enough power to the cutting system of the pruner to cut the 1.5" maximum branch diameter, a test must be performed. For this test, branch samples will be used which have an approximate diameter of 1.50". Since the pruner is expected to be used in an orchard environment, the test samples will include 5 apple branches (wet and dry) and 5 cherry branches (wet and dry). The test branches will also include a 1 spruce branch and 1 other evergreen branch for test sample variety. During the maximum branch test cuts, the cycle time

of a cut when cutting the maximum branch size will be measured, using a stopwatch. It is expected that the cycle time of a cut will increase when cutting a maximum size branch. However, the cycle time of the cut must be no longer than the required 2.0 seconds. The temperature of the power system when cutting maximum diameter branches will also be measured using a thermocouple.

## 2. Endurance Branch Cutting :

To ensure that the power system of the pruner can remain under 110° F when cutting at a rate of 250 1" diameter branches/ hour, a test must be performed. It is impractical to attempt to obtain 250 green (wet) branches for the sake of testing the power system temperature. However it is practical to obtain 25 green branches for the testing process. A thermocouple will be attached to the actuator of the power system to record how the temperature of the system changes when consecutively cutting 25 1 inch branches of the different varieties (apple, cherry, and spruce). The data from this test can be analyzed using Microsoft Excel. A predictive plot can be made from the test data to determine what the power system temperature would be after 250 consecutive cuts.

## Deliverables:

The testing of pruner power system will take place during the first week of spring quarter 2016. This testing will follow the construction of the pruner prototype. The following weeks of spring quarter will be allotted for the testing of the other divisions of the pruner projects, housing and ergonomics, and the cutting system. The test data for all sections will be documented in the Appendix.

## Budget/Schedule/Project Management

### Proposed Budget

In the design requirements for the pruner power system, it is established that the total cost of all components and construction should be no more than \$700. A summarized table of the quantity and cost of all pruner system components can be found in **Appendix C1**. It can be seen in the appendix that the power system components actually cost \$162 less than the previously proposed budget for the power system. This is mainly due to the selection of a new drive system, Makita, which has been a better choice in every single, including cost. Although the redesign process has placed a major time constraint on the pruner team, it has spurred further optimization and practicality for the pruner design.

### Proposed Schedule

A high level Gantt chart which establishes the proposed schedule of the pruner project is included in **Appendix E1**. The primary milestones included in the chart are listed below:

1. Fall Quarter Proposal Finished – 12/9/15

2. Proposal Revisions – 12/18/15
3. Prototype Construction Complete – 3/15/15
4. Testing/Evaluation – 6/8/15

The project should take 223 hours in total. This total is calculated from the Gantt chart displayed in the **Appendix K1**

## **Project Management**

### **Human Resources:**

- The construction of the pruner power system relies heavily on the cooperation of the Hogue Technology Building's lab technician, Matt Burvee. Mr. Burvee's assistance and expertise in the machine shop is extremely valuable to the progress of construction. The cooperation of our team with Mr. Burvee will ensure that we have frequent access to the machine shop and will be prioritized above other groups with regards to effort
- Professors Greg Lyman and Christopher Hobbs are crucial resources for the construction of the circuit which will be required for the cutting cycle to operate correctly. They will consult the power system division of the pruner team to ensure that appropriate circuit components are purchased for the pruner trigger circuit.
- Professor Johnson is a crucial resource for assistance with stress and failure analysis. His expertise will help ensure the pruner team does not overlook any aspects of design, with regard to strength and stress analysis.
- Professor Pringle is another important resource for information and guidance with design decisions and analysis. Professor Pringle's expertise will help the pruner team in the production of a successful product.

### **Physical Resources:**

- The machine shop of Hogue Technology Building
- The materials lab of Hogue Technology Building
- The Construction Management Testing Lab
- The foundry of Hogue Technology Building

### **Software Resources:**

- Multisim circuit builder
- Dassault Solidworks
- Microsoft Excel

### **Financial Resource:**

- Neil Hauff, president of H.F. Hauff Co. Inc.: Neil is willing to pay for justified design decisions and components. At the beginning of winter quarter, the pruner team will meet with Neil Hauff to discuss what components will require funding. Design decisions will be justified to Mr. Hauff through specification sheets, empirical testing data, and analysis performed by the pruner team.

## Discussion

### Design Evolution/Performance Creep

As the design process moves into the prototype construction phase, aspects of the original proposed design may have to be changed to accommodate unforeseen factors. As the process moves forward, the design changes and evolution will be recorded.

Many aspects of the original design finalized at the end of the end of fall quarter have been changed. A few changed are listed below:

1. Instead of purchasing a linear actuator, the team is now using a Makita impact driver as the primary source of torque for a custom-made actuator.
2. Instead of using the Pellenc battery back which was used for the Treelion, the pruner team will now utilized the dual-port charging pad for the Makita LXT series. This pad will be converted into a mobile battery pack with two 5 Ah Makita batteries hooked together in parallel.
3. Instead of have the main driver be at the far end the Makita is now located in the approximate middle of the pruner and a “double-pistol grip” handle system will now be used as per request of the financier.

### Project Risk Analysis

One risk involved with the current design process is the potential for the final design to not be easily mass-produced. The KV21 linear actuator may not easily purchased in mass quantities for a decent price and it may not be feasible when the pruner design goes to production level.

Another risk of the current pruner design is the possibility that a battery system may have to be purchased/produced. The battery system to be used in the current design is the Treelion 44VDC battery belt design by Pellenc, the parent company of Treelion. A new battery system may result in changes in design due to supply voltage, battery weight, battery life of the different battery system.

### Successful

If the prototype of the pruner proves to be a successful design, with regard to design requirements, testing results, and success criteria, the design may be acknowledged by Neil Hauff to be a product to be mass-produced. In this next phase of design, the ascetics and features of the pruner design would be improved and re-designed.

### Next Phase

The next phase of the design process is to construct a working prototype of the pruner power system. After the power system is manufactured, it will then be assembled with the cutting system components and the housing components constructed by the other members of the pruner design team.

## Conclusion

The problems with the original Treelion pruner used by Emmanuel Maniadakis can be summarized in the list below:

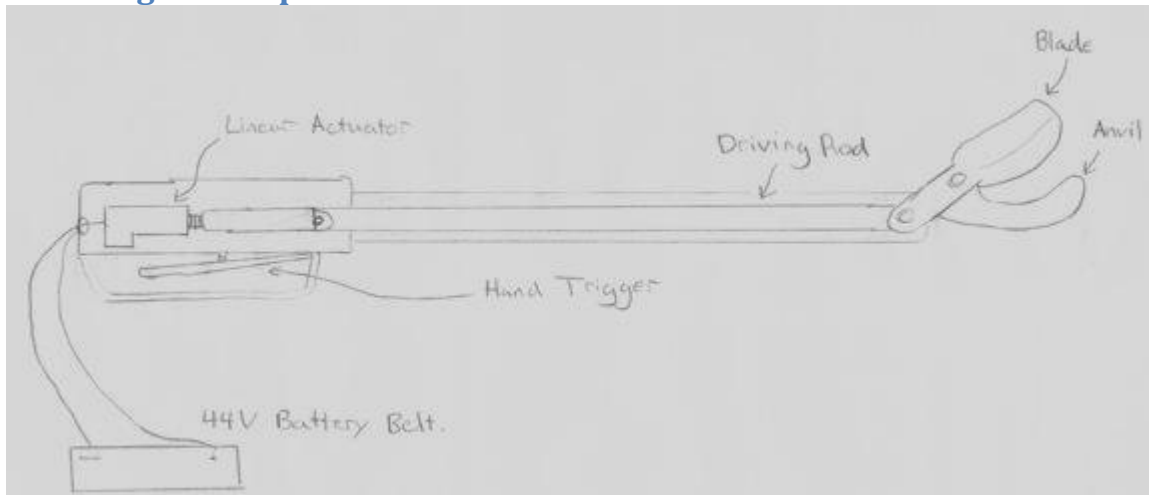
- The device is too hot to hold on to.
- The trigger system is uncomfortable.
- The “hold trigger to keep cutting” feature of the Treelion is not comfortable or practical.
- It’s not long enough.

The new design of the Hauff pruner will solve these problems involved with pruner use and performance summarized in the list below:

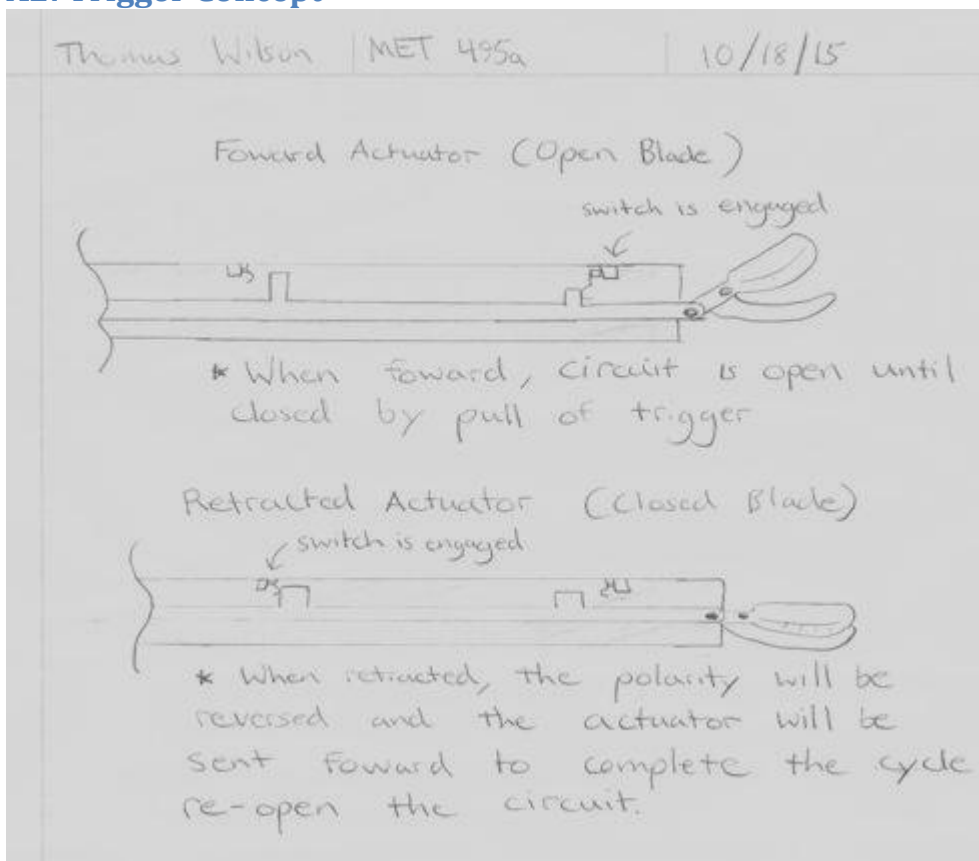
- The pruner actuator/motor and surrounding housing will not exceed a temperature of 110°F after cutting a maximum branch size of 1.50 in. or cutting 250 1 in. diameter branches/hour for 1 hour.
- The “single-finger” trigger system that was not comfortable for the user before is replaced with a 4-finger hand trigger in the new design.
- The trigger system will now require only a momentary pull which initiates the cutting cycle of the pruner.
- The pruner design will has a length of 36 in. from the top of the trigger to end of the blade.

## Appendix A – Analyses

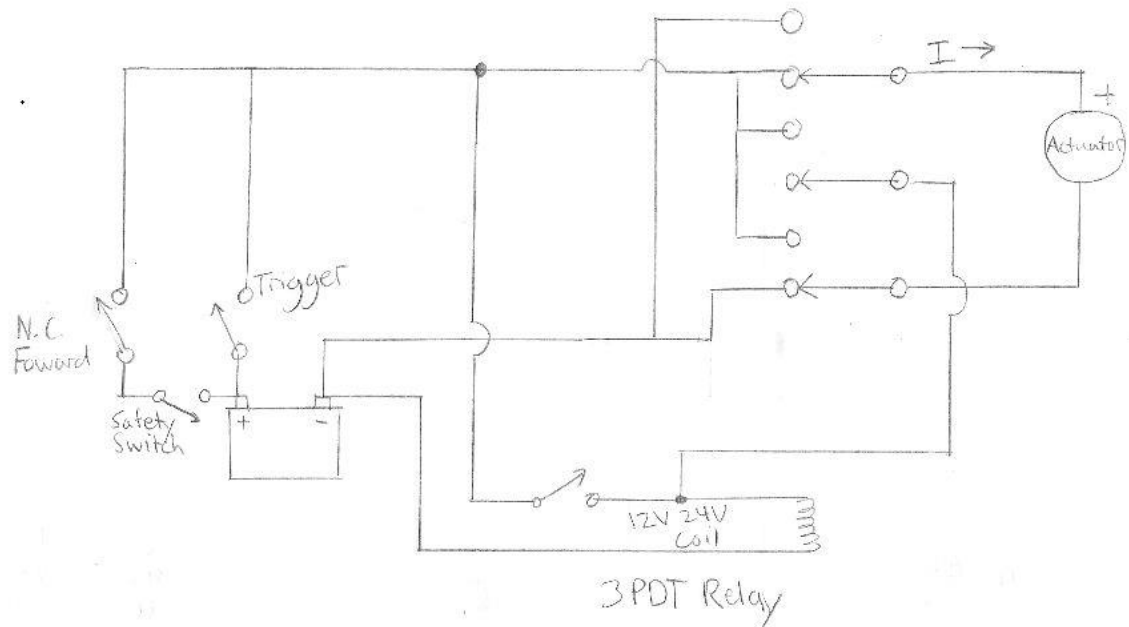
### A1: Design Concept



### A2: Trigger Concept



### A3: Trigger Circuit Drawing



### A4: Duty Cycle Calculation

Duty Cycle of Cutting Force Device

Given: Cutting Force device  
 Cut Cycle time =  $2.0s = t_1$   
 Time between cycles =  $8.0s = t_2$

Find:  
 Duty Cycle:  $D$

Solution:

$$D = \left[ \frac{t_1}{(t_1 + t_2)} \right] \cdot 100 = \left[ \frac{2.0s}{(2.0s + 8.0s)} \right] \cdot 100$$

$\Rightarrow D = 20\%$

Therefore, a duty cycle of no greater than 20% is required for cutting force device

## A5: Mechanical Power Output

Thomas Wilson | MET 495A | 10/11/15

Mechanical Power Output

Given: Cutting force device:

Cutting Cycle time,  $t_1 = 2.0s$       Source Voltage,  $E_s = 44V$   
stroke length (One way),  $L = 2in$   
Force required for cut,  $F_c = 450 lb$

Find: a) Mechanical Power output of Cutting force device,  $P_o$  (W)  
b) Resulting Current

Solution: First, linear velocity of stroke:

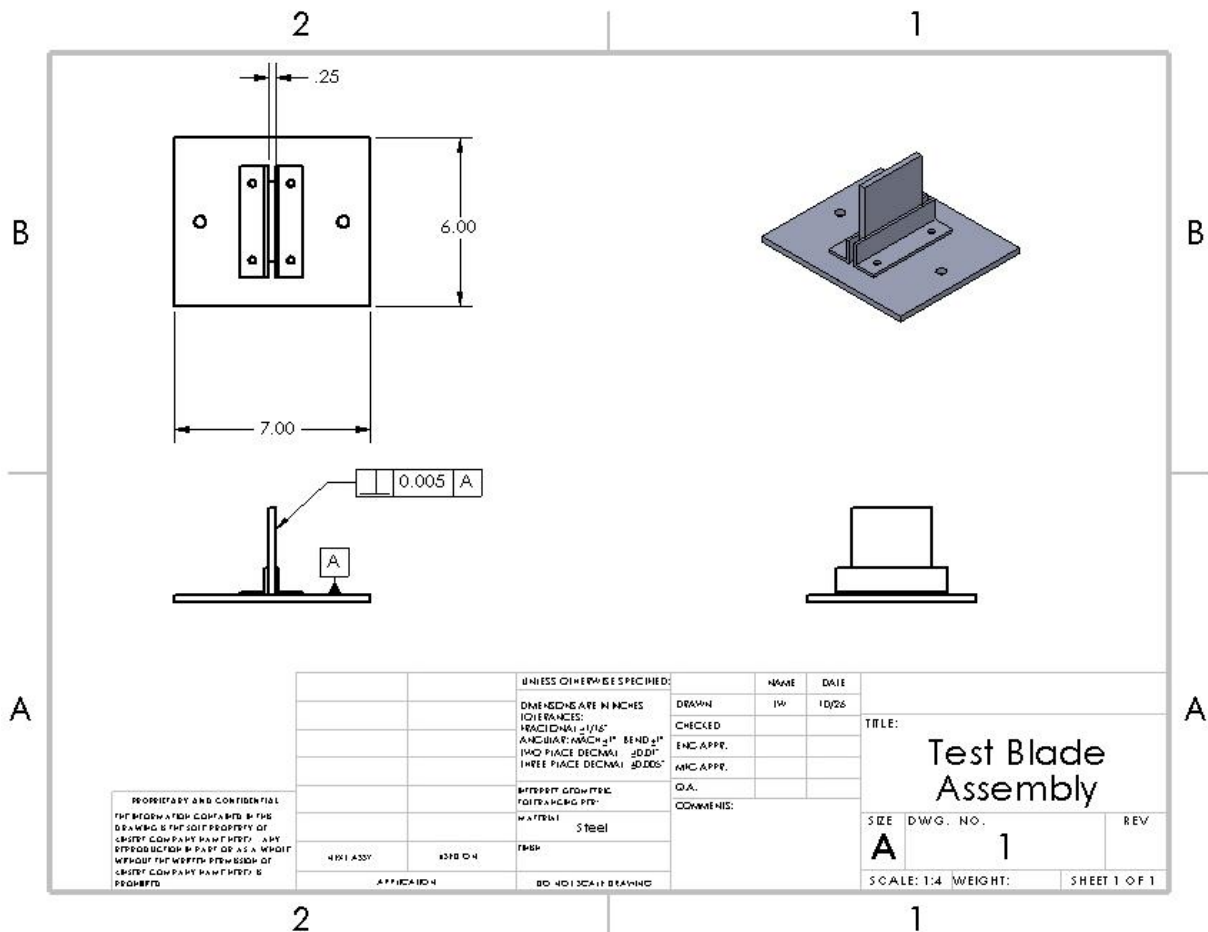
$$V = \frac{2in}{2.0s} = 1in/s$$

a) Power output:

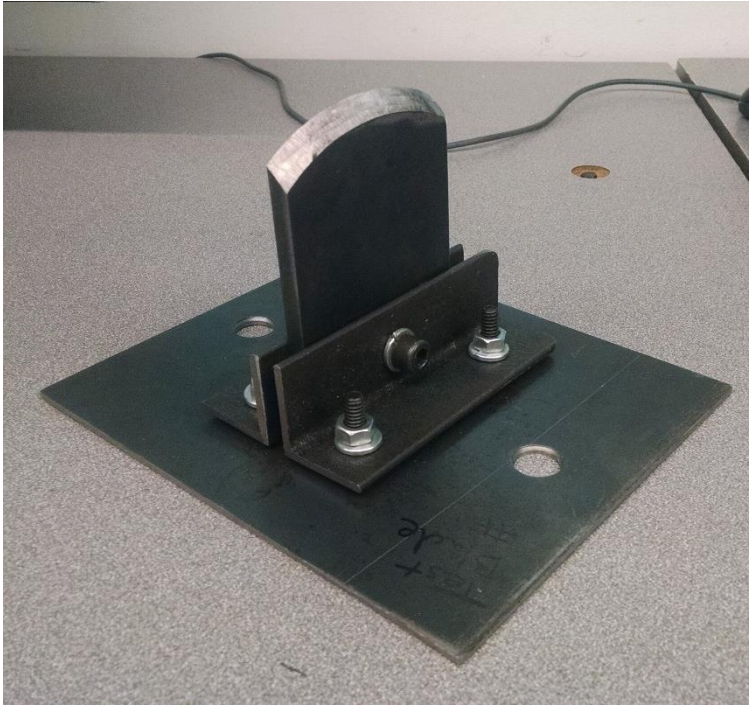
$$P_o = F_c \cdot V$$
$$= 450 lb \cdot \frac{1in}{s} = 450 \frac{lb \cdot in}{s}$$
$$P_o = 450 \frac{lb \cdot in}{s} \cdot \left( \frac{1 foot}{12 in} \right) \cdot \left( \frac{1 HP}{550 \frac{ft \cdot lb}{s}} \right) \cdot \left( \frac{746 W}{1 HP} \right)$$

$$\Rightarrow P_o = 50.9 W$$

## A6: Test Blade Assembly (Testing Round #1)



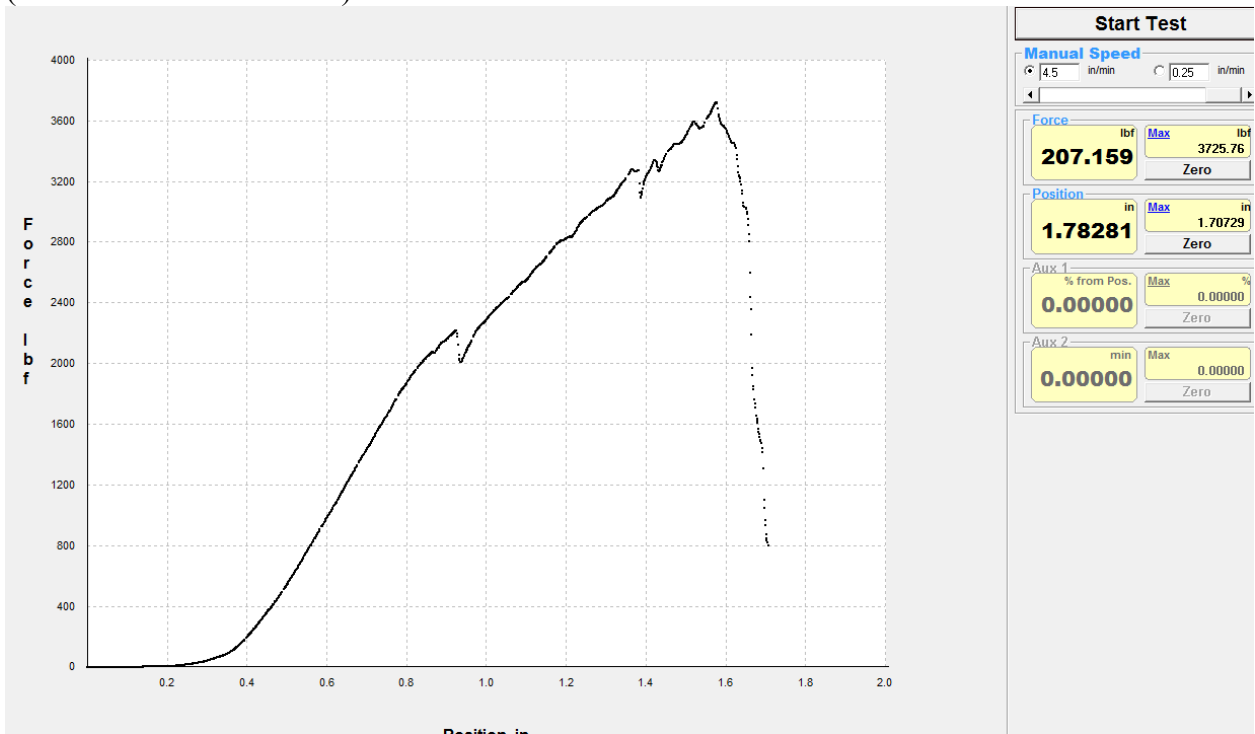




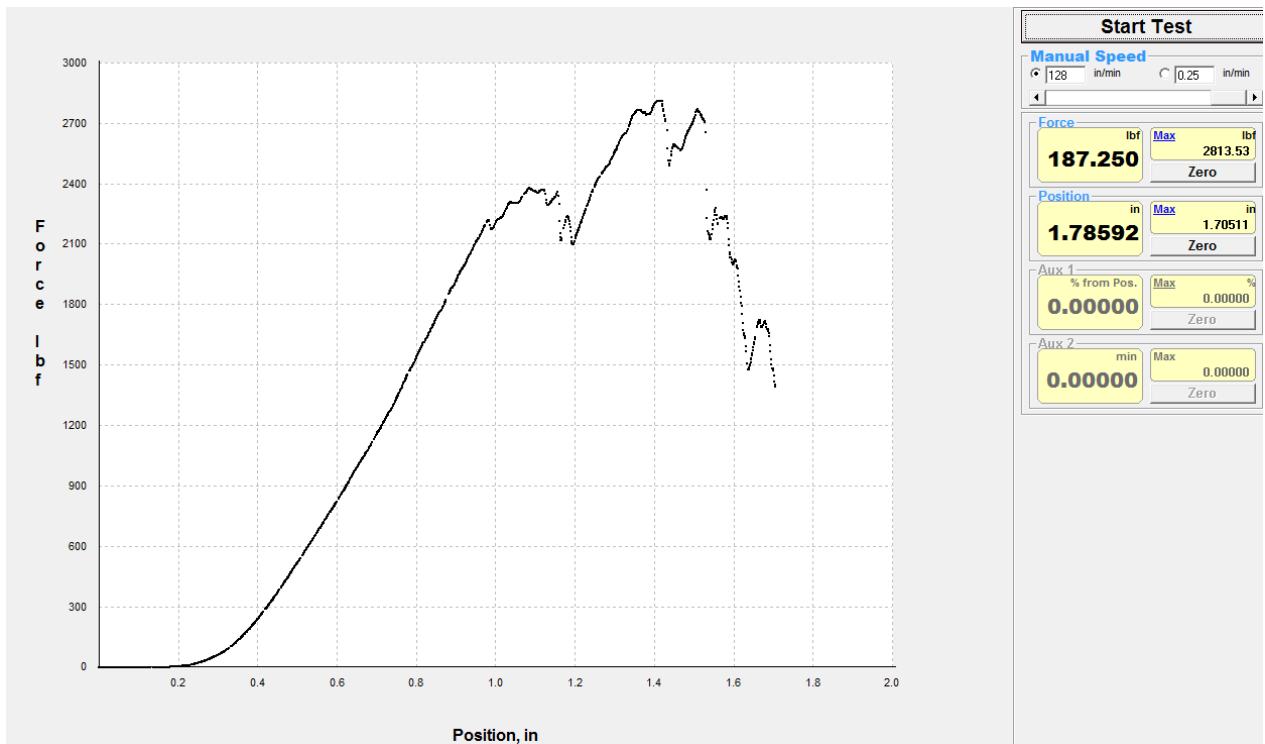
### A7: Cutting Test Data (Testing Round #1)

The graphs displayed below show the force required during the cut of various sizes of plum branches.

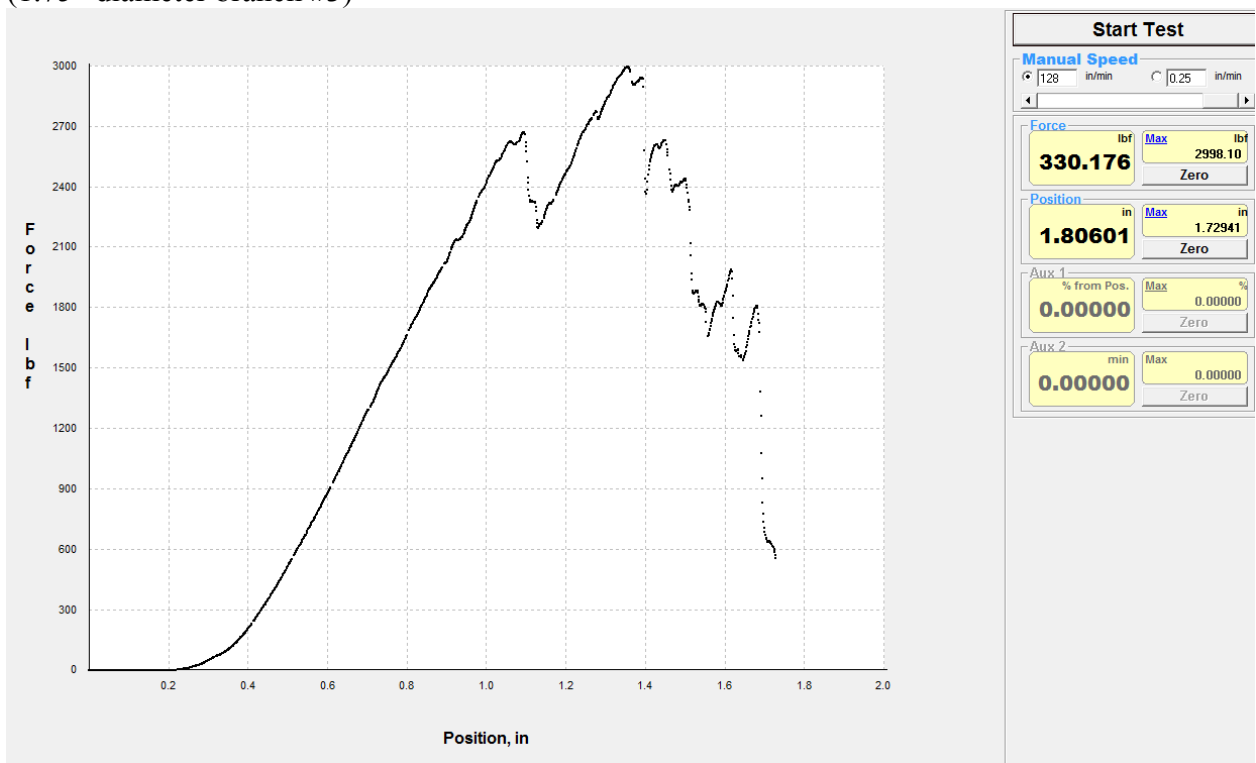
(1.75" diameter branch #1)



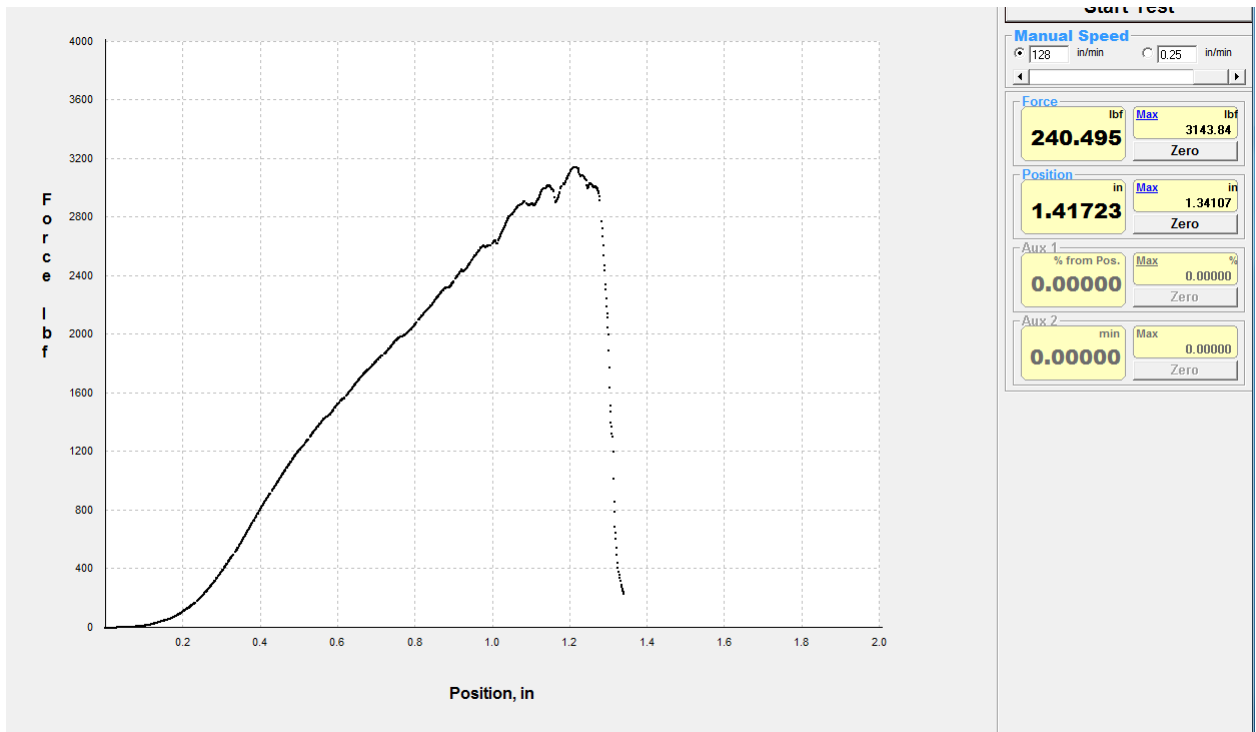
(1.75" diameter branch #2)



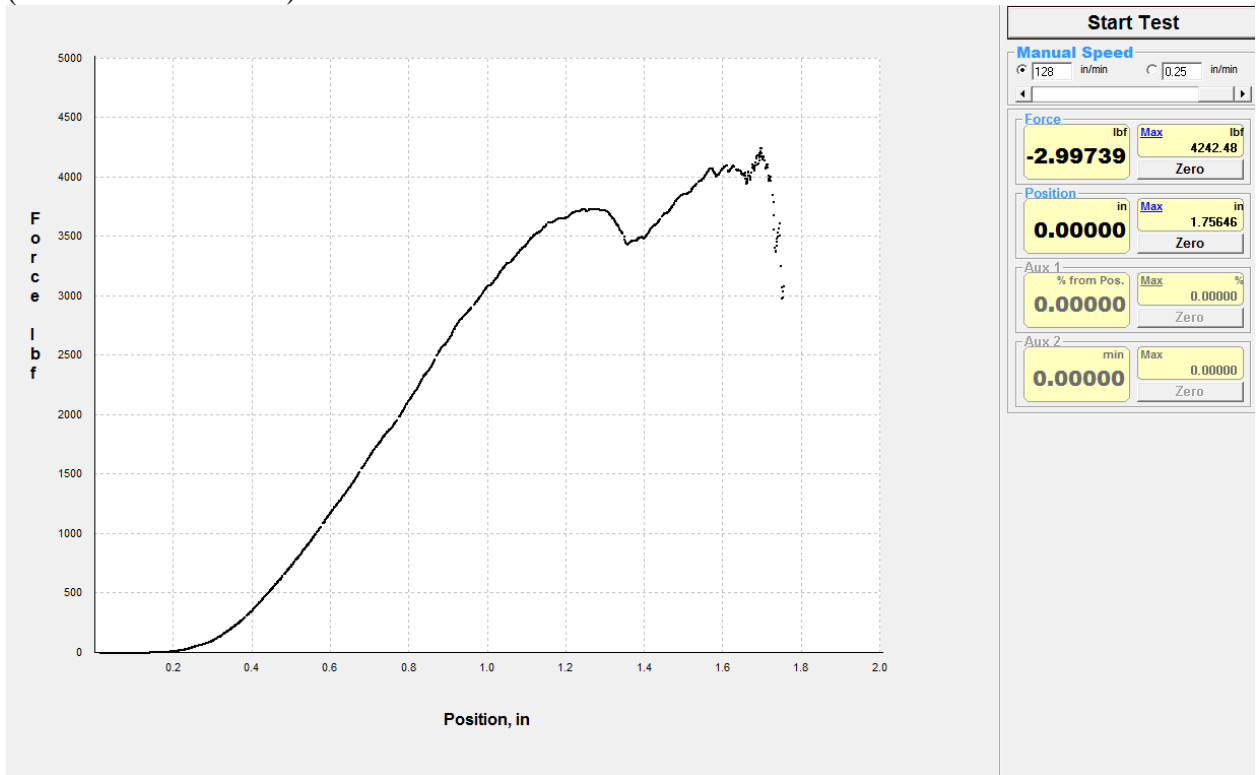
(1.75" diameter branch #3)



(1.25" diameter branch)

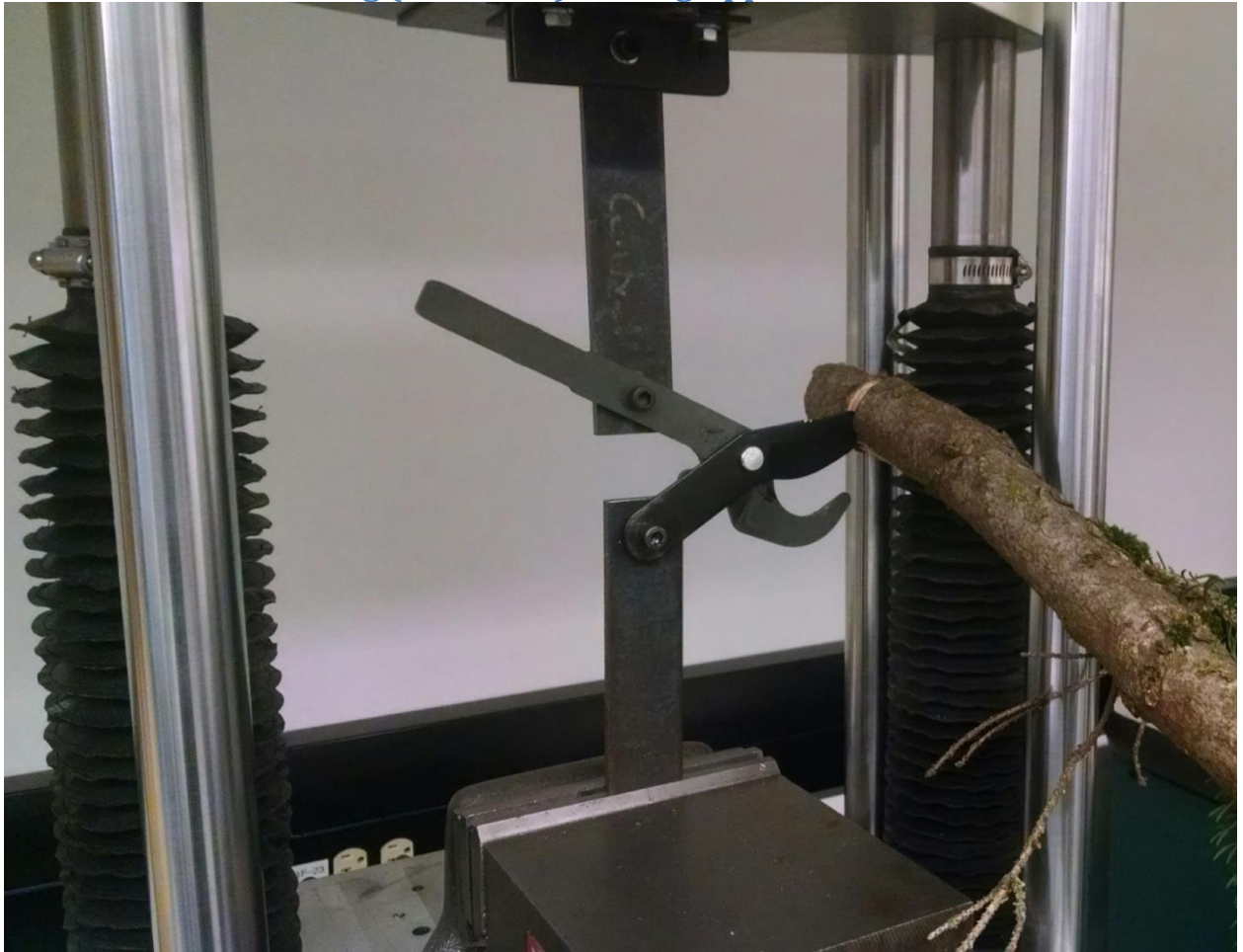


(1.8" diameter branch)



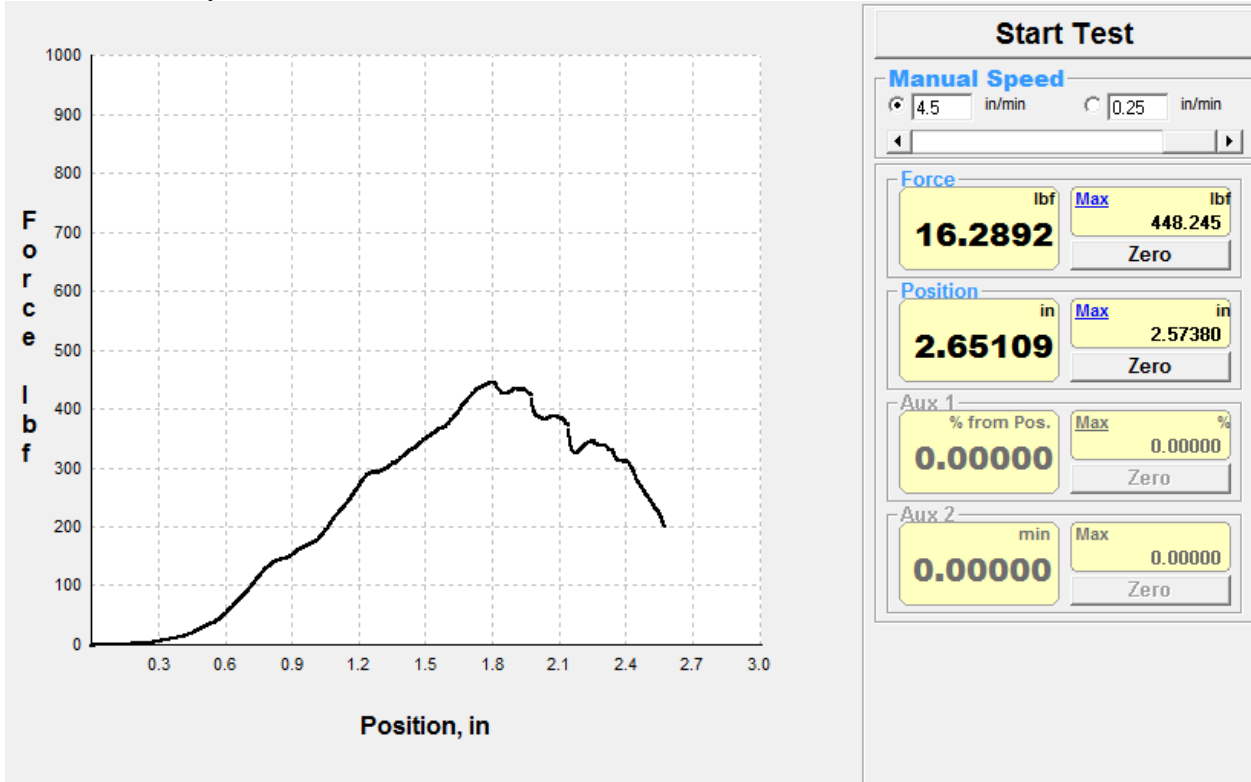


### A8: Tree Branch Testing (Round #2) Testing Apparatus

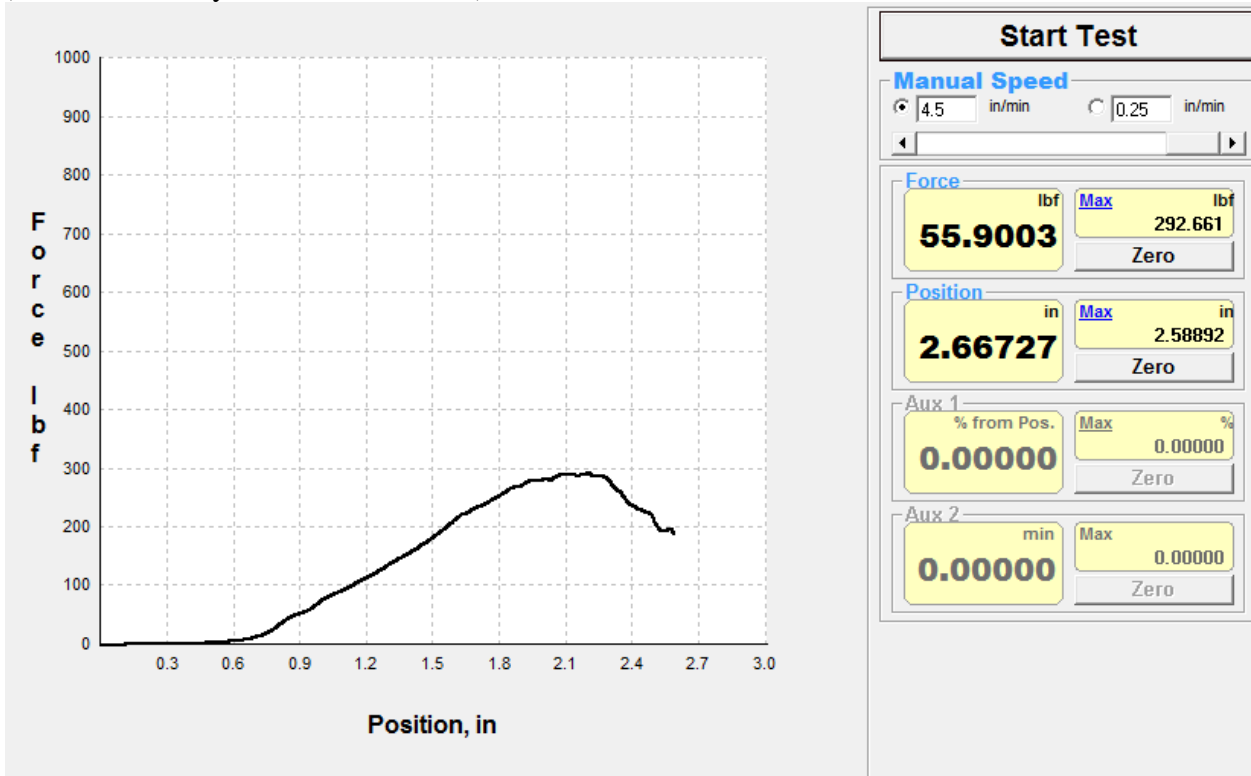


## A9: Tree Branch Testing (Round #2) Data

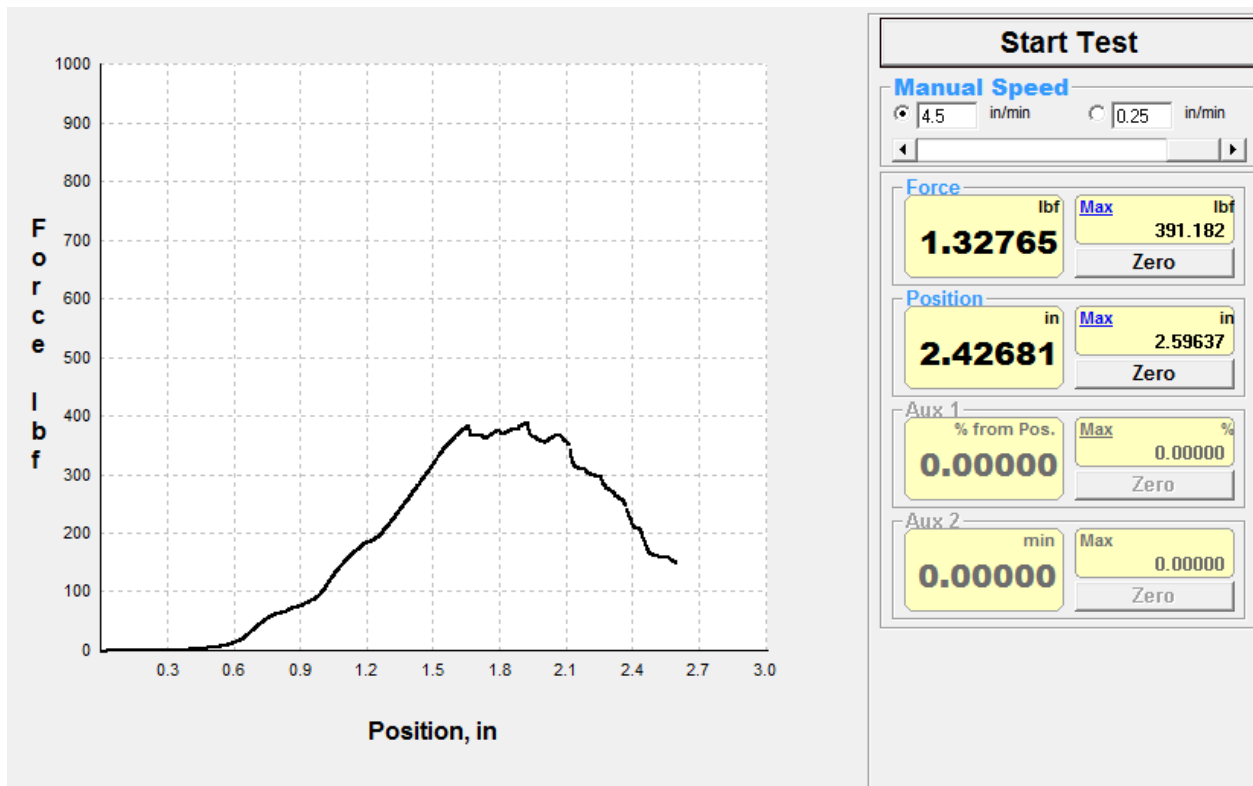
(Test #1 - Cherry – 1.50 in Diameter)



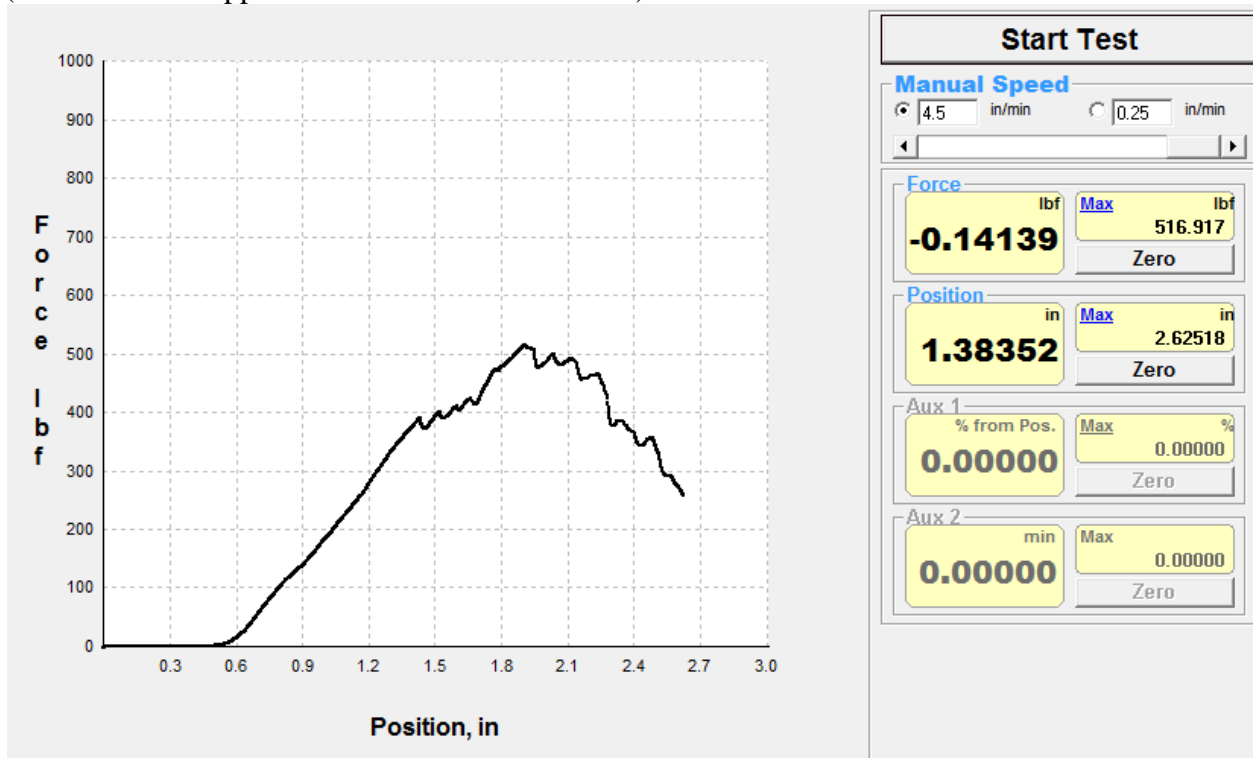
(Test #2 – Cherry – 1.34 in Diameter)



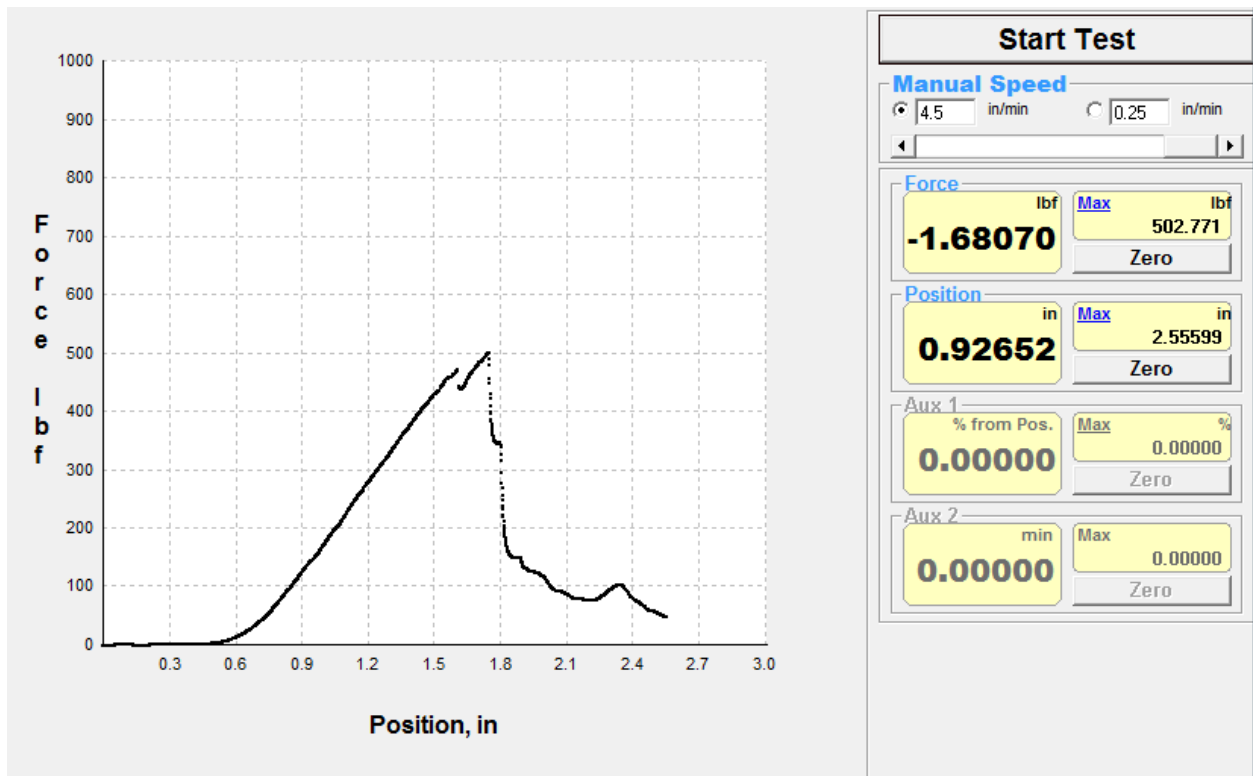
(Test 3 – Cherry – 1.52 in. Diameter)



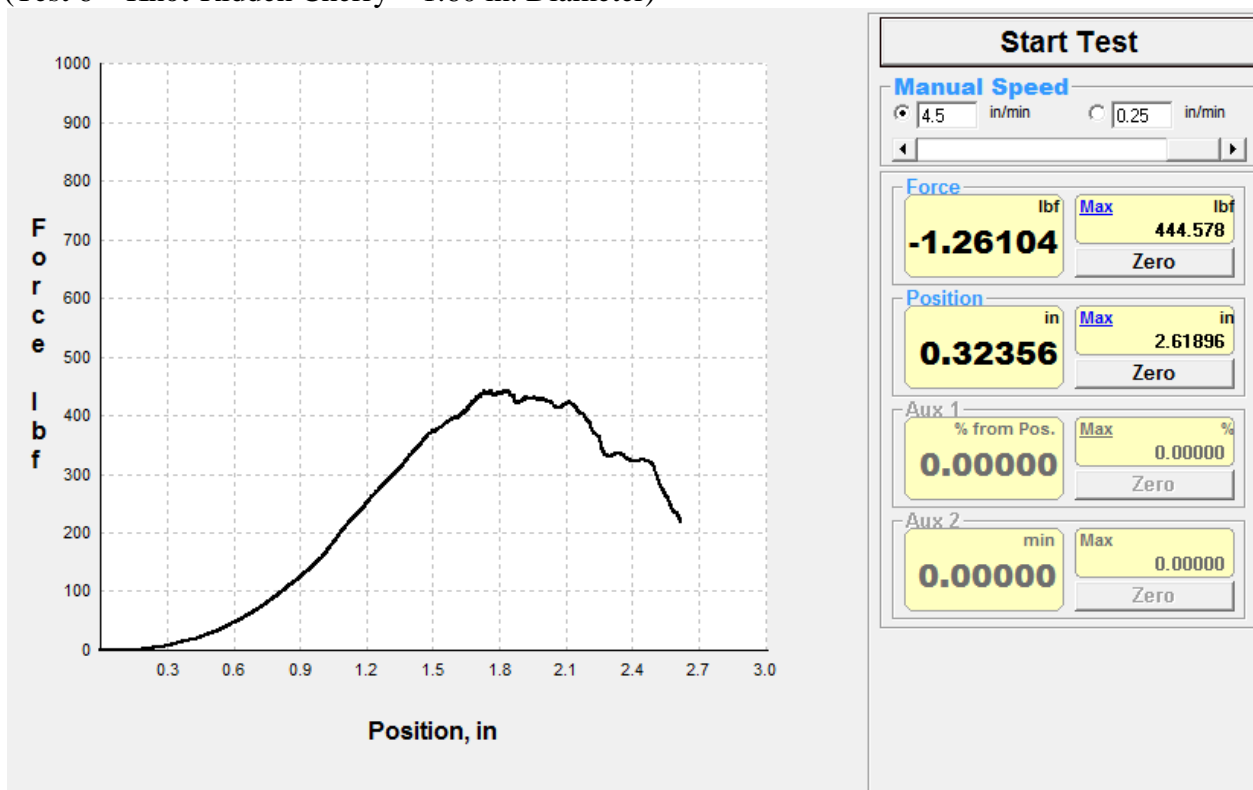
(Test 4 – Dead Apple Branch – 1.30 in. Diameter)



(Test 5 – Spruce – 1.28 in. Diameter)



(Test 6 – Knot-Ridden Cherry – 1.60 in. Diameter)





## A10: Maximum Required Force Blade Orientation Calculation

Thomas Wilson

A10

Tinius Olsen downward velocity =  $4.5 \text{ in/min} \cdot \left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 0.075 \text{ in/s}$

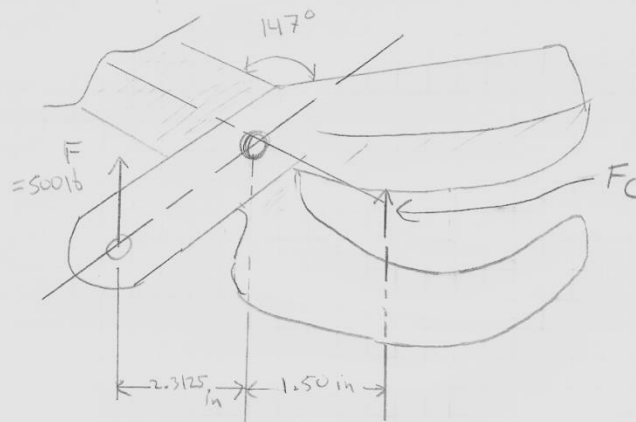
Tinius Olsen distance where most force is required on 1.50 in Cherry branch = 1.8 in

Time into test when most force required:

$$\frac{0.075 \text{ in}}{1 \text{ s}} = \frac{1.8 \text{ in}}{t} \Rightarrow t = \left(\frac{1.8 \text{ in}}{0.075 \text{ in/s}}\right) \Rightarrow t = 24 \text{ s}$$

- In test video, 24s into cut the Fiskars is at the following orientation:

Therefore we know, most force is required at this orientation and cutting point is approximately 1.50 in from pin



## A11: Average Cutting Point Force Calculation

Thomas Wilson	Cutting Point Force	A11
$\sum M_B = 0: F_A(1.5in) - (500lb)(2.3125in) = 0$		
$F_A = \frac{500lb(2.3125in)}{1.5in} \Rightarrow F_A = 770.83 lb$		

## A12: Actuator Pin Sizing Calculation

Actuator Pin Sizing

1020 Cold Rolled Steel

55 Ksi =  $S_y$

Eqn. 2-3 (Mott)  
 $S_{ys} = S_y / 2 = 27.5 \text{ Ksi}$   
 yield strength in shear

Endurance Factor (Safety Factor)  
 Eqn 5-5 (Mott)  
 $S_{ys} = 27.5 \cdot (0.50) \text{ Ksi}$   
 $S_{ys} = 13.75 \text{ Ksi} = T_{max}$

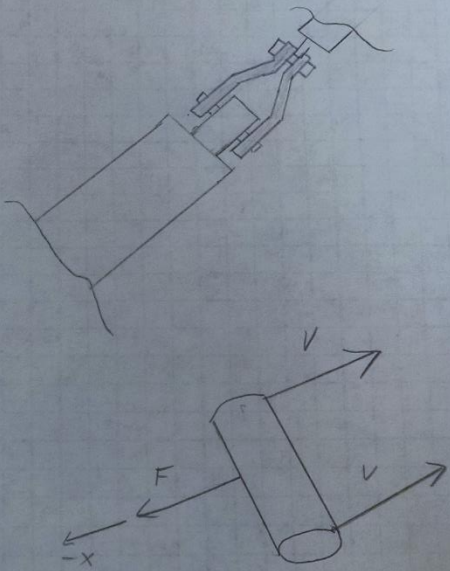
$T_{max} = \frac{V}{A} = \frac{V}{\frac{\pi}{4} D^2}$

$\Rightarrow D = \sqrt{\frac{V}{T_{max} (\frac{\pi}{4})}}$

$\Rightarrow D > \sqrt{\frac{25016}{13.75 \text{ Ksi} (\frac{\pi}{4})}}$

$\Rightarrow D > 0.152''$

$\Rightarrow D = \frac{1}{4}''$



$\pm \rightarrow \sum F_x = 0: -F + 2V = 0$   
 $\Rightarrow V = \frac{F}{2} = \frac{50016}{2} = 25016$

## A13: Aluminum vs. Carbon Fiber Driving Rod

Thomas Wilson

Option 1:

Carbon Fiber Driving Rod:  
Rockwell Composite standard modulus:

$$\sigma_{max} = 700 \text{ ksi}$$

$$\sigma_{max_1} = \frac{700 \text{ ksi}}{1.5} \Rightarrow \sigma_{max} = 467 \text{ ksi}$$

Option 2:

Aluminum Driving Rod:

AlSI 6061  
 $\sigma_{max} = 8 \text{ ksi}$

$$\sigma_{max_2} = \frac{8 \text{ ksi}}{2} \Rightarrow \sigma_{max_2} = 4 \text{ ksi}$$

$$d = \sqrt{D^2 - \frac{4F}{\sigma \pi}}$$

Option 1: AlSI 6061

$$d = \sqrt{0.75 \text{ in}^2 - \frac{4(600 \text{ lb})}{4 \times 10^3 \text{ lb/in}^2 \cdot \pi}}$$

$$\Rightarrow d = 0.610 \text{ in}, \Rightarrow \text{Area} = 0.29 \text{ in}^2$$

Therefore thickness  $t_1 > 0.1405 \text{ in}$

Tube to use: "onlinemetals" price: \$47.96

$$\text{weight} = \rho \cdot \text{Vol}$$

$$= 0.0975 \frac{\text{lb}}{\text{in}^3} \cdot (0.29 \text{ in}^2 \cdot 24 \text{ in})$$

Option 2: Carbon Fiber

$$\text{weight} = 0.68 \text{ lb} = 0.31 \text{ kg}$$

$$d = \sqrt{0.75 \text{ in}^2 - \frac{4(600 \text{ lb})}{700 \times 10^3 \text{ lb/in}^2 \cdot \pi}} = 0.750 \text{ in}$$

$$\Rightarrow t_1 > 0.0073 \text{ in}, \rho = 0.0578 \frac{\text{lb}}{\text{in}^3}$$

$$\text{weight} = \rho \cdot \text{Vol} = (0.0578 \frac{\text{lb}}{\text{in}^3})(0.29 \text{ in}^2 \cdot 24 \text{ in})$$

$$\Rightarrow \text{weight} = 0.402 \text{ lb}$$

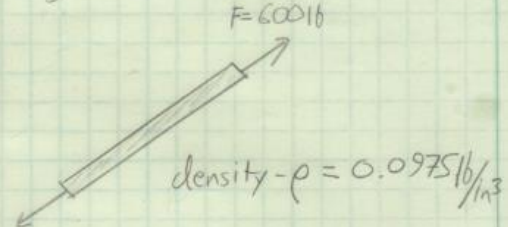
Summary

	Carbon Fiber	Aluminum
weight	0.402 lb	0.68 lb
price	\$25.98	\$47.96
thickness req'd	0.0073 in	0.1405 in

Figure 1: Cross-section



Figure 2:



## A14: Carbon Fiber Driving Rod Tension Sizing

### Driving Rod - Tensile Strength Sizing

#### GIVEN

Driving Rod:  
OD = D = 0.75 in

Material - Carbon Fiber  
Clear Water Composites

$S_y = 200 \text{ ksi}$        $P = 600 \text{ lb}$

#### FIND:

minimum T for driving rod

#### SOL'N:

$$\sigma_{\text{allow}} = \frac{S_y}{2} = \frac{200 \text{ ksi}}{2} = 100 \text{ ksi}$$

$$A = \frac{\pi}{4} (D^2 - d^2)$$

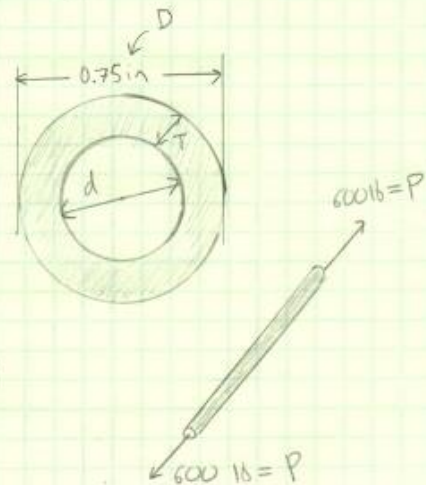
$$\sigma_{\text{allow}} = \frac{P}{A} = \frac{P}{\frac{\pi}{4} (D^2 - d^2)}$$

$$(D^2 - d^2) = \frac{P}{\sigma_{\text{allow}} \left( \frac{\pi}{4} \right)} \Rightarrow d = \sqrt{D^2 - \frac{P}{\sigma_{\text{allow}} \left( \frac{\pi}{4} \right)}}$$

$$\Rightarrow d = \sqrt{0.75^2 - \frac{600 \text{ lb}}{100 \text{ ksi} \left( \frac{\pi}{4} \right)}}$$

$$\Rightarrow d = 0.74 \text{ in}$$

Therefore  $\boxed{t > 0.01 \text{ in}}$





## A15: Collar Stress Concentration Calculation

### GIVEN

Driving rod collars  
Dimensions in Figure 1

### FIND:

Will SAE 1020 cold-drawn  
appropriate material?

Design factor =

$$S_y = 51 \text{ ksi} \Rightarrow S_{y\text{actual}} = \frac{51 \text{ ksi}}{1.25}$$

$$\Rightarrow S_{y\text{actual}} = 40.8 \text{ ksi}$$

Stress concentration factor from  
efatigue.com,  $1.94 = K_t$

Blade end collar will have greatest  
stress due to smaller cross-sectional  
area at fillet.

Max stress @ fillet =

$$\sigma_{\text{max}} = K_t \frac{F}{A}$$

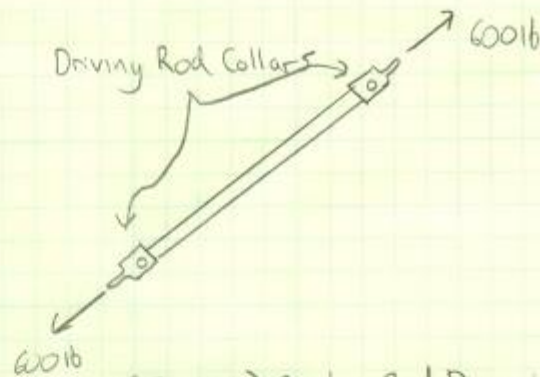
$$= 1.94 \left( \frac{600 \text{ lb}}{0.8 \text{ in} - 0.130 \text{ in}} \right)$$

$$\Rightarrow \sigma_{\text{max}} = 11.19 \text{ ksi}$$

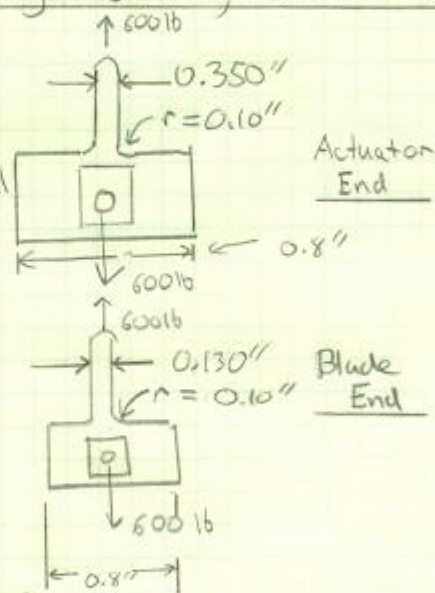
$$\sigma_{\text{max}} (11.19 \text{ ksi}) < S_{y\text{actual}} (40.8 \text{ ksi})$$

Therefore, fillet radius and material is acceptable.

\*SAE 1020 cold-drawn is cheap and available



(Figure 1) Driving Rod Dimensions



## A16: Driving Rod Linkage Width Sizing

### Driving Rod Linkage Sizing

Given Driving Rod linkage dimensions  
(Figure 1)

Safety factor =  $N = 2$

Material SAE 1020

Load =  $P = 2$

REQ'D:

minimum  $w$ , width of linkage  
SOL'N:

$S_y$  OF SAE 1020 Cold drawn,

$S_y = 51 \text{ ksi}$  (MUT)

$$S_y' = \frac{S_y}{N} = \frac{51 \text{ ksi}}{2} = 25.5 \text{ ksi}$$

$$\text{Area} = A = (w - 0.138'') - (0.25 - 0.138')$$

$$\Rightarrow A = 0.138'' (w - 0.25)$$

$$\sigma_{\text{max}} = S_y' = 25.5 \text{ ksi}$$

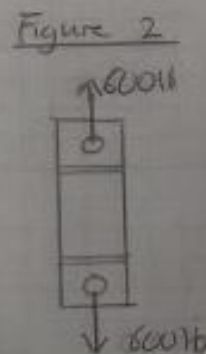
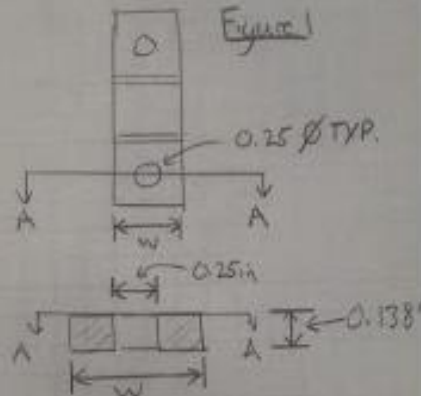
$$\sigma_{\text{max}} = \frac{F}{A} = \frac{F}{0.138'' (w - 0.25)}$$

$$\Rightarrow w = \left[ \frac{F}{\sigma_{\text{max}} \cdot 0.138''} \right] - 0.25 \text{ in}$$

$$\Rightarrow w = \left[ \frac{600 \text{ lb}}{25.5 \text{ ksi} \cdot 0.138''} \right] - 0.25 \text{ in}$$

$$\Rightarrow w \geq 0.738 \text{ in}$$

Therefore, a width of  $\frac{3}{4}''$  is acceptable for the linkage width.



## A17: Driving Rod Buckling Analysis

### Driving Rod - Buckling Analysis

#### GIVEN

Driving Rod in Figure 1  
Experiences max. actuator load of 600 lb when trying to open blade but can't (Compression)

#### REQ'D

Will tube buckle under max load

#### SOL'N

Using Matt's design system for buckling columns:

#### Radius of Gyration:

$$r = \sqrt{I/A} = r = \sqrt{\frac{0.015 \text{ in}^4}{0.245 \text{ in}^2}} = 0.247 \text{ in}$$

#### Slender Ratio:

$K = 1.0$  for double-pinned column

$$S.R. = \frac{KL}{r} = \frac{(1.0)(30 \text{ in})}{0.247 \text{ in}} = 121.4$$

#### Column Constant

$$C_c = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2 \cdot 30 \text{ E}6 \text{ lb/in}^2}{200 \text{ E}3 \text{ lb/in}^2}}$$

$$\Rightarrow C_c = 54.4$$

$$S.R. > C_c \Rightarrow \text{LONG COLUMN}$$

#### Critical load:

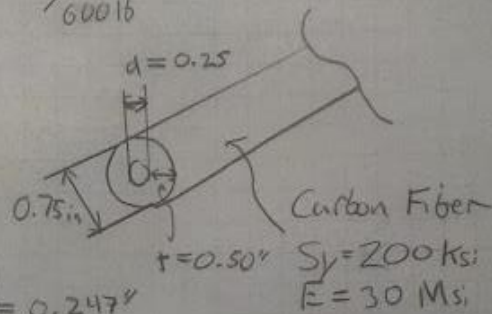
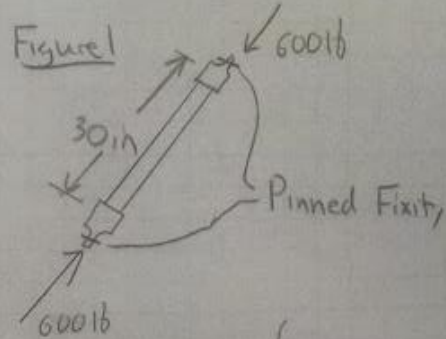
$$P_{cr} = \frac{\pi^2 EA}{(KL/r)^2}$$

$$\Rightarrow P_{cr} = \frac{\pi^2 (30 \text{ E}6 \text{ lb/in}^2)(0.245 \text{ in}^2)}{(121.4)^2} = 4922.09 \text{ lb}$$

#### Allowable load:

$$P_a = \frac{P_{cr}}{N} = \frac{4922.09 \text{ lb}}{2}$$

$$\Rightarrow P_a = 2,461.04 > 600 \text{ lb}$$



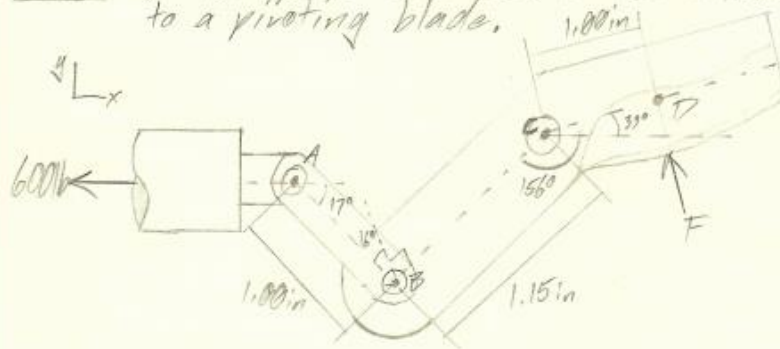
Therefore, tube dimensions established for tension of rod allow for an acceptable buckling load.

Rod will not buckle under max. compression



## A18: Cutting Point Force Calculation

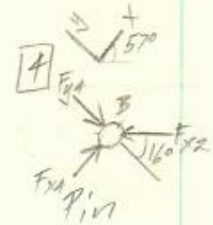
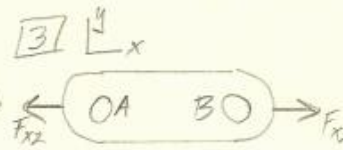
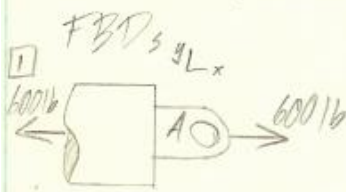
Given: A rod pulls with 600 lb on a linkage pair attached to a pivoting blade. The blade reacts the linkage at



The blade reacts on the branch at D. The angle configuration shown in the figure is where the most force is required when cutting the branch. Pin C is fixed and the rod only moves on an x-axis.

Find: Force applied to branch  
Dimensions of linkages  
Dimensions of pins

Sol'n: Force applied to branch (F)



$$\boxed{2} \rightarrow \sum F_x = 0: F_{x2} - (600 \text{ lb}) \cos(17^\circ) = 0$$

$$F_{x2} = 573.7829 \text{ lb} \rightarrow$$

$$\uparrow \sum F_y = 0: F_{yz} - (600 \text{ lb}) \sin(17^\circ) = 0$$

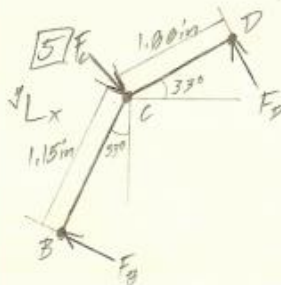
$$F_{yz} = 175.4230 \text{ lb} \uparrow$$

$$\boxed{4} \rightarrow \sum F_x = 0: F_{x4} - (573,752916) \sin(16^\circ) = 0$$

$$F_{x4} = 158,156016 \rightarrow$$

$$+\sum F_y = 0: -F_{y4} + (573.782916) \cos(16^\circ) = 0$$

$$F_{y4} = 557.553516 \downarrow$$



$$\begin{aligned} \sum M_c = 0: & -F_D(1.15 \text{ in}) + F_D(1.00 \text{ in}) = 0 \\ F_D = & (557.5555 \text{ lb})(1.15 \text{ in}) \end{aligned}$$

$$F_B = F_{y4}$$

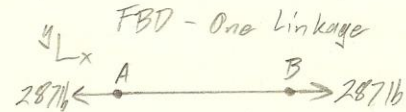
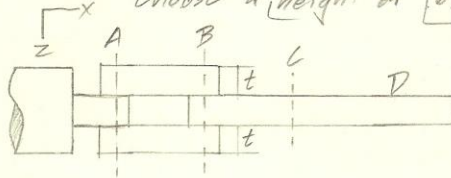
$$F_D = 634.2588 \text{ lb}$$

$$F = 63416$$

## A19: Shear Pin Sizing for Cutting System Pin

### Linkage Dimensions

Choose AISI 1018 steel and design to yield strength ( $s_y = 49 \text{ ksi}$ )  
 Choose a height of  $0.625 \text{ in}$ .



safety factor of 1.5

$$F = (1.5)(287 \text{ lb})$$

$$\sigma = \frac{F}{A}$$

$$s_y = \frac{F}{bh} \Rightarrow t = \frac{F}{s_y h}$$

$$t = \frac{(1.5)(287 \text{ lb})}{(49000 \frac{\text{lb}}{\text{in}^2})(0.625 \text{ in})}$$

$$t = 0.01406 \text{ in}$$

$$\sigma = s_y$$

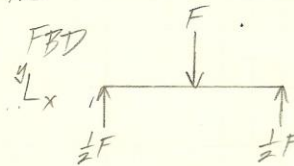
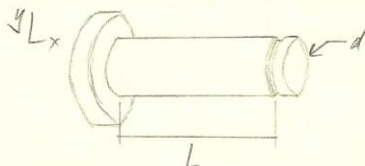
$$A = bh$$

$$b = t$$

Choose a standard thickness of  $0.125 \text{ in}$  for the linkages. Consider using a cheaper material with a lower yield strength.

### Pin Dimensions

Choose Clevis Pins  
 Choose AISI 1018 steel and design to yield strength ( $s_y = 49 \text{ ksi}$ )  
 Use a safety factor of 1.5



Pin A (Double Shear)

$$\tau = \frac{F}{2A}$$

$$s_y = \frac{F}{2A} \Rightarrow A = \frac{F}{2s_y}$$

$$d = \sqrt{\frac{2F}{\pi s_y}}$$

$$d = \sqrt{\frac{2(1.5)(600 \text{ lb})}{\pi (49000 \frac{\text{lb}}{\text{in}^2})}}$$

$$d = 0.1081 \text{ in}$$

Pin B (Double Shear)

$$d = \sqrt{\frac{2F}{\pi s_y}}$$

$$d = \sqrt{\frac{2(1.5)(573.7829 \text{ lb})}{\pi (49000 \frac{\text{lb}}{\text{in}^2})}}$$

$$d = 0.1057 \text{ in}$$

Assume thicknesses of rod connection and blade are  $0.15 \text{ in}$ .

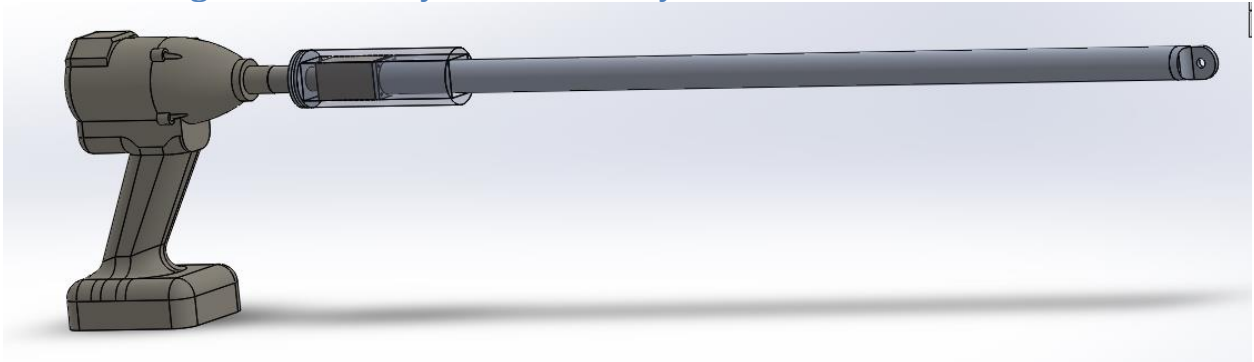
$$L = 2(0.125 \text{ in}) + (0.15 \text{ in})$$

$$L = 0.40 \text{ in}$$

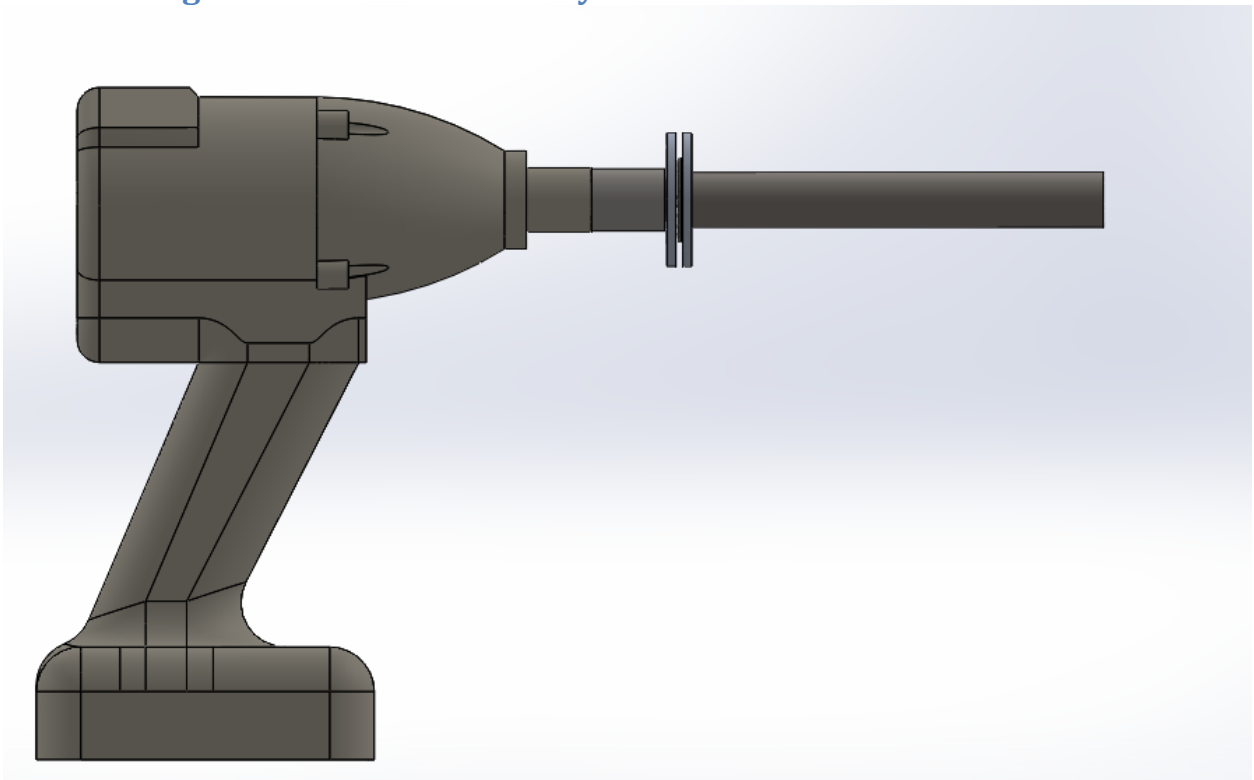
For both pins A and B, use a standard diameter of  $0.25 \text{ in}$  and a usable length of  $0.40 \text{ in}$ . Consider using a cheaper material.

## Appendix B – Power System Drawings

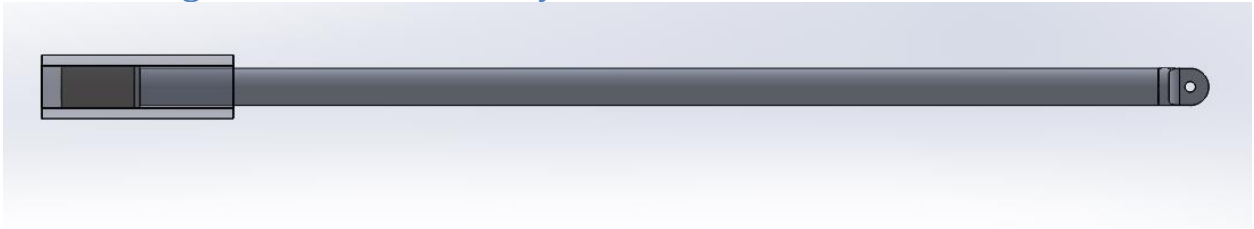
### B1: Drawing A1 – Power System Assembly



### B2: Drawing A2: Ball Screw Assembly



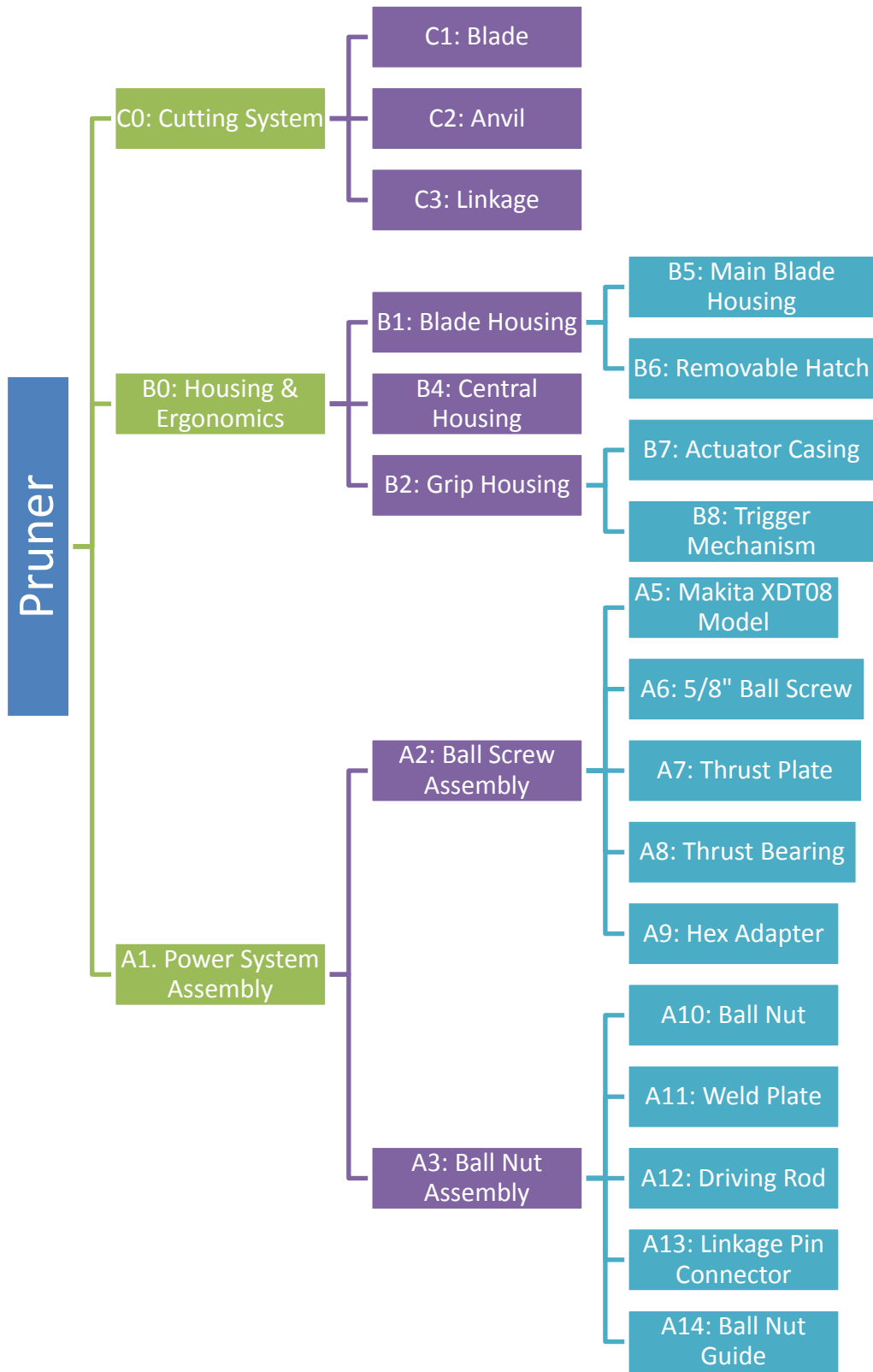
### B3: Drawing A3: Ball Nut Assembly



**B4: Drawing A4: Makita Dual-Port Charger**



## B15: Hauff Pruner Drawing Tree



## Appendix C – Parts List

### C1: Parts and Price List

	Part	Dimensions	Supplier	Price	Quantity	Subtotal
Cutting System	Nickel Titanium	.0160" x 2.50"	NDC	\$448.00/foot	1	\$448.00
	SAE 1018 Cold Rolled	.125" x .5"	Online Metals	\$1.21/foot	1	\$1.21
	Grooved Clevis Pin with Retaining Ring	D 3/16" x L 1/2"	McMaster-Carr	\$5.49/5 units	1	\$5.49
Housing & Erg.	Cabon Fiber Filament Wound Tube	OD 1.5" x ID 0.75"	Rock West Composites	\$116.99/foot	2	\$233.98
	Light Duty Dry-Running Sleeve Bearings	OD 3/4" x ID 5/8" x L 3/4"	McMaster-Carr	\$0.89/unit	2	\$1.78
	Aluminum	3" square bar	Online Metals	\$122.72/foot	1	\$122.72
	Rubber Coating	11oz/5ftsq. coverage	Home Depot	\$5.98/can	1	\$5.98
	Screws	3/8" 2-56 #1 Drive	McMaster-Carr	\$5.70/50 screws	1	\$5.70
Power & Trans.	Makita XDT08 Impact Driver	N/A	Home Depot	\$119.00	1	\$119
	Makita 5 Ah 18V Battery	N/A	Home Depot	\$219.00	1	\$219.00
	Makita Dual-Port Charger	N/A	Home Depot	\$109.00	1	\$109.00
	Ball Screw	5/8" OD 13/64" Lead	McMaster-Carr	\$19.47/ foot	1	\$19.47
	Ball Nut	13/64" Lead WxL = 1" x 1"	McMaster-Carr	\$31.85	1	\$31.85
	Thrust Bearing	1/2" ID .940" OD	McMaster-Carr	\$3.11	1	\$3.11
	Aluminum Plate	.125" Thick 12 x12	Online Metals	\$12.64		\$12.62
	Aluminum Tube	L12" x OD .875" x ID .777"	Online Metals	\$5.82/foot	3	\$17.46
	Aluminum Stock	L12" x OD .875"	Online Metals	\$6.41	1	\$6.41

## Appendix D – Budget

Power & Trans.	Makita XDT08 Impact Driver	\$119
	Makita 5 Ah 18V Battery	\$219.00
	Makita Dual-Port Charger	\$109.00
	Ball Screw	\$19.47
	Ball Nut	\$31.85
	Thrust Bearing	\$3.11
	Aluminum Plate	\$12.62
	Aluminum Tube	\$17.46
	Aluminum Stock	\$6.41
	Total Cost of Power System Components	\$538
	Total Budget For Power Syster	\$700
	Amount Under Budget	\$162

## Appendix E – Schedule

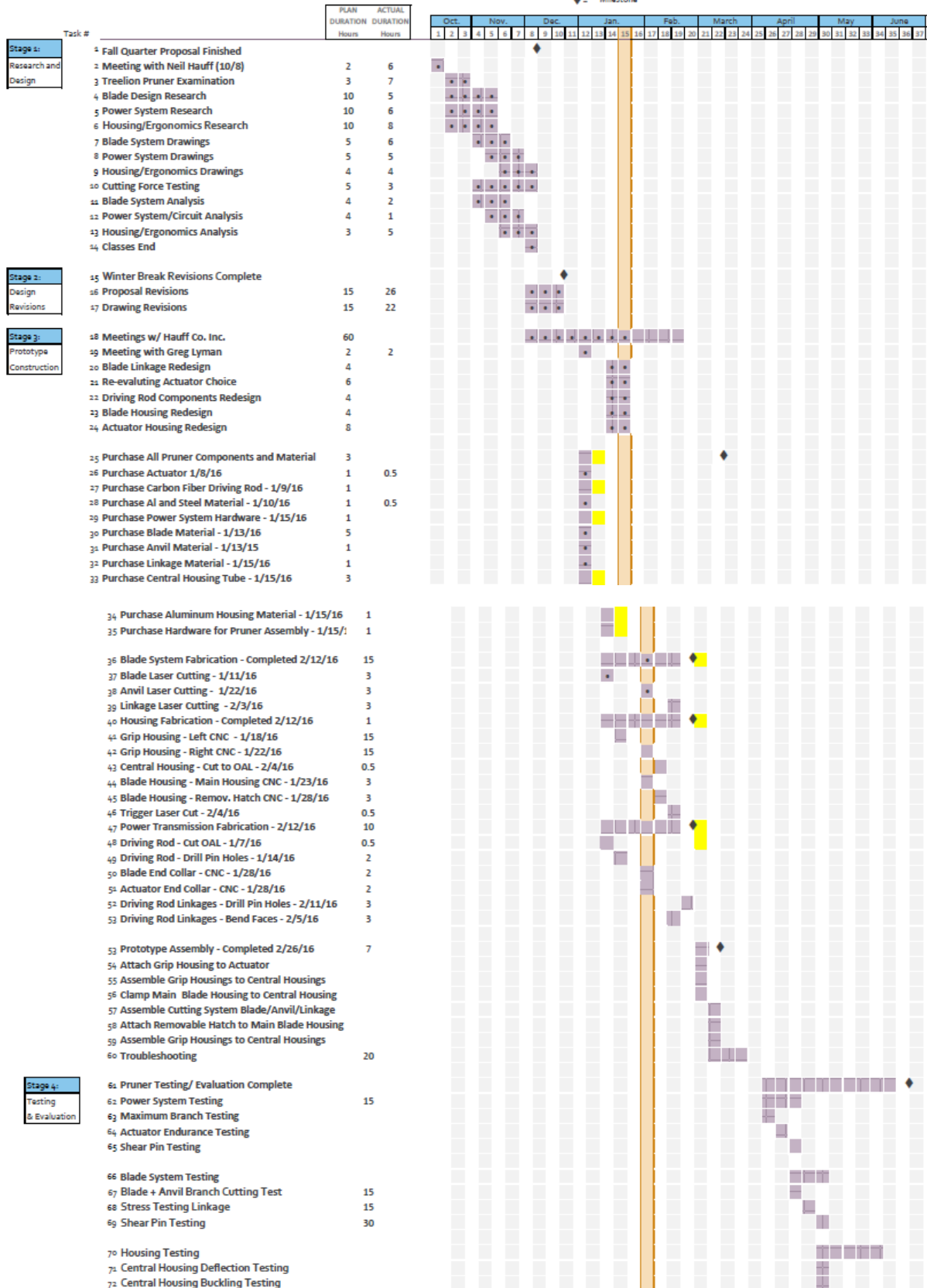


## H.F. Hauff Pruner

### Project Schedule

Period Highlight: #

- = completed task
- = Behind schedule
- ◆ = Milestone







## Appendix F – Expertise and Resources

Neil Hauff – President, H.F. Hauff Co. Inc.

Dr. Craig Johnson – Central Washington University

Professor Charles Pringle – Central Washington University

## Appendix G – Testing Data

This Appendix will contain the testing data following the construction of the prototype.

## Appendix H – Evaluation Sheet

This appendix will contain evaluation sheet of pruner.

## Appendix I – Testing Report

### Introduction:

#### Requirements:

The Requirement of the power system of the pruner which will be tested are listed below:

- Pruner power system must be able to make 250 7/8"- 1" diameter branch cuts in 1 hour
- Pruner power system must supply enough power to cut through a 1.5" diameter branch.
- The power system must supply cutting force for 1,000 7/8" to 1" diameter branch cuts
- Weight: under 7 lb.
- Cutting cycle should be no longer than 2 seconds.

#### Parameters of Interest:

The parameters of interest for the power system of the pruner are listed below:

- Battery Life (Number of cuts per charge)
- Weight

- Max. Branch Cut

### Predicted Performance:

#### Cut cycle time:

- Using the specifications of the linear motion ball screw and the Makita XDT08, it was predicted that the total open-close-open cycle of the pruner cutting blade would be **1.67 seconds**. To determine this, the resulting linear operating speed of the driving rod had to be determined. The calculation for this is shown below:

$$\begin{aligned} \text{Linear Speed} &= \frac{\left( \text{RPM} * \text{Lead} \left( \frac{\text{in}}{\text{rev}} \right) \right)}{60} \\ &= \left( (800 \text{ RPM}) * \left( .203 \frac{\text{in}}{\text{rev}} \right) \right) * \frac{1 \text{ min.}}{60 \text{ seconds}} = 2.71 \text{ in./s} \end{aligned}$$

Now that the linear speed of the driving rod during an operational rotational speed of 1,000 RPM was determined. The cut cycle time could be found by multiplying the required stroke length (2.23 in.) by 2 to account for the forward and backward motion of the driving rod. Then, the total travel distance was divided by the linear operating speed of the driving rod to determine the predicted cycle time, 1.67 seconds. (See Testing Appendix 1 for Excel calculations)

#### Weight:

- The predicted weight of all power system components was predicted using the material mass features of Dassault Solidworks modeling software. The weight of the Makita XDXT08 impact driver unit was found in the product specifications, as was the weight of the battery, linear motion ball screw, and ball nut. The 3D models of these components were altered so they could represent the true weight of the components in the 3D environments. The total predicted weight of all the power system components was **5.87 lb.**

#### Quantity of Branch Cut per Hour:

- The number of branches which could be cut in 1 hour was determined in a simplified fashion, using the predicted value of time for 10 branch cuts. This time value for 10 branch cuts was determined to be **52.7 s**. This was determined by multiplying the cut cycle time by 10 and adding 4 seconds in between each cut to accommodate real-world conditions.

#### Thrust Output of Ball Screw System:

- The thrust output of the ball screw system is predicted to follow the relationship specified in the following equation:

$$\text{Driving Torque} = \frac{\text{Lead of Screw} * \text{Thrust load} * \text{Screw Efficiency}}{2 * \pi}$$

The testing procedure explained below provides a predicted value as an example.

### Data Acquisition:

#### Cut Cycle Time:

- The data for the cut cycle time will be acquired using a stop watch to record the cut

cycle time.

**Weight:**

- The weight of the power system has been acquired using a scale.

**Branch Cut Rate:**

- The rate of cut branches data is acquired by using a stop watch to time how long it takes to cut 10 branches.

**Maximum Branch Cut:**

- The maximum branch cut data is acquired through observing the operation of the unit during a maximum branch cut.

**Thrust Output:**

- The data for the thrust output of the pruner will be determined through the usage of point-load cell and load cell unit.

**Schedule:**

The attached Gantt chart lists the dates and predicted times for the different tests:

- Cut Cycle Time : See “Complete Pruner Testing” ID: 61
- Weight: See “Power System Testing” ID: 62
- Branch Cut Rate: See “Complete Pruner Testing ID:61
- Maximum Branch Cut: See “Complete Pruner Testing ID:61
- Thrust Output: See “Power System Testing” ID: 62

**Method/Approach:**

The methods used to acquire, record, and report the testing data are explained below:

**Resources:**

The primary resources for testing are listed below:

- Matt Burvee: Mr. Burvee provided assistance with testing setup and manufacturing of testing components for the thrust output testing procedure.
- Hogue Technology Building Machine Shop: Tools, materials, and equipment were used in the machine shop to construct the setup for the thrust output testing.
- Greg Lyman and the EET Department: With the assistance of Greg Lyman and the EET department, it was possible to acquire load data from the Point-load cell unit.
- D.J. Gibson: Mr. Gibson provided assistance with data collection for the maximum branch cut, branch cut rate, and weight testing.
- Erich Heilman: Mr. Heilman provided assistance with data collection in the maximum branch cut and branch cut rate testing.

**Data Capture/Doc/Processing**

The methods for data capture, documentation, and processing are listed below:

**Branch Cut Rate:** This testing was accomplished by recording the time it takes to cut down the length of a single branch 10 times. The diameter of the branch ranged from 7/8” to 1”. A stopwatch was used to record the time as 10 cuts were taken from the single branch. The time started at the beginning of the first cut and ended at the end of the 10<sup>th</sup>

cut. The recorded times were then processed in Microsoft Excel to determine the average cutting time for the three trials. (See Testing Appendix 2 for Excel Calculations)

**Weight:** The weight of the power system components was observed and recorded using a soil scale from the Construction Management department. The total weight of the power system components was recorded in Excel.

**Cutting Cycle Time:** The time it takes to complete a cutting cycle with the pruner power system was recorded using a stopwatch. The stopwatch would start when the blade of the pruner was in the full open position and end after the cut had been completed and the blade returned to the open position. Three trials were performed. The average cutting time of the three trials was recorded as the testing value.

**Thrust Output:** The thrust output of the ball screw system was initially acquired through the usage of a point-load cell. The load value on the load cell unit was recorded on paper for the five testing trials. Microsoft Excel was used to find the average of the 5 testing trials.

**Maximum Branch Cut:** The data for the maximum branch cut test was acquired through visual observation and recorded on paper and in the testing report.

## Test Procedure Overview

The overview for the 5 testing procedures are listed below:

**Branch Cut Rate:** The branch cut rate testing is completed by recording the time it takes to make 10 7/8" to 1" diameter branch cuts. This test includes 3 testing trials.

**Weight:** The weight test is completed by recording the weight of all pruner power system components when placed on a scale.

**Cutting Cycle Time:** The cutting cycle time test is completed by recording the time it takes for the power system of the pruner to complete 1 cutting cycle (blade open→ blade close→ blade re-open). This test includes 3 testing trials.

**Thrust Output:** The thrust output test of the ball screw system is completed by measuring and recording the linear thrust output of a known input torque on the ball nut, using a point-load cell. This test includes 5 testing trials.

**Maximum Branch Cut:** This maximum branch cut test is completed by observing and recording whether or not the power system of the pruner is successful in providing enough linear output torque to cut a 1.5" diameter branch.

## Operational Limitations

The operational limits for the testing procedures are listed below:

**Branch Cut Rate:** One operational limit of the branch cut rate test is time. There is not enough time allotted in the testing schedule to actually try and cut 250 branches in 1 hour.

The stopwatch used in the cycle time test is only able to record to the nearest .001 second. However this is satisfactory for this test.

**Cutting Cycle Time:** The stopwatch used in the cycle time test is only able to record to the nearest .001 second. However this is satisfactory for this test.

**Thrust Output:** The accuracy of the thrust output test is limited by the data tolerance of the point-load cell unit. This tolerance is  $\pm .05$  lb.

**Maximum Branch Cut:** The power system components may not be able to withstand the stresses involved in the maximum branch cut despite the preliminary design and analysis of the components. This could lead to re-design or more manufacturing of previous parts.

### Precision and Accuracy Discussion

The precision of the stopwatch used in the cut cycle time and branch cut rate testing is to the nearest 0.001 second. The accuracy of the stopwatch reading is obviously limited by the reaction time of the stopwatch user. This is a potential source of error. The point-load cell unit used in the thrust output relationship test has an accuracy tolerance of  $\pm 0.5$  lbs.

### Data Storage/Manipulation/Analysis

**Branch Cut Rate:** For this test, data was stored both on engineering paper and in an Excel spreadsheet form. The timed trials of 10 cuts were manipulated into an average value using Excel. This average value was then analyzed against the predicted value for Branch cut rate.

**Weight:** For the weight test, data was stored directly into the engineering report. The recorded weight value was analyzed in regards to the predicted weight value.

**Cutting Cycle Time:** For this test, data was stored both on engineering paper and in an Excel spreadsheet form. The timed trials of the timed trials were manipulated into an average value using Excel. This average value was then analyzed against the predicted value for cutting cycle time.

**Thrust Output:** For the thrust output test, the data was stored on both engineering paper and in an Excel spreadsheet. The values from the 5 thrust output trials were averaged to get a final testing value.

**Maximum Branch Cut:** The visual observations of this test were recorded directly into the testing report and the observations were checked against predictions.

### Data Presentation

The data for the 5 testing procedures are displayed in the testing report and they are summarized in the “Testing” section of the Engineering Report.

## **Testing Procedures:**

### **Thrust Output Testing:**

Test Duration: 2 hours

Place: Hogue Technology Building Machine Shop

Testing Procedure:

1. Isolate the following power system components in single assembly; Makita head, 7/16” hex nut driver, hex-adapted ball screw, ball nut, driving rod attachment.
2. Using the screw holes in the Makita head piece, fasten it to the first mounting plate, making sure the bottom of the head component is facing the bottom of the mounting bracket.
3. Place a small amount of grease in the pilot hole of the other mounting bracket and insert the end of the driving rod in the pilot hole.
4. Position the ball screw/Makita assembly and both mounting plates on the way-table of the Bridgeport milling machine.
5. Uses a square to ensure that both mounting plates are perpendicular to the edge of the table and use blocks and screw to firmly mount the plates to the Bridgeport table.
6. Place the point-load cell in between the Makita-head mounting bracket and the rear stop. Make sure the load cell is as close to the center of the line of action as possible.
7. Without any pressure on the load cell, tare it out.
8. Turn the ball nut make the ball screw to make the ball screw assembly tight within the two brackets. The load cell should read between 30 – 50 lbs. for the initial clamping pressure.
9. Place the mini-torque arm on the ball nut.
10. Hook the Fish-scale hook to the hook hole of the mini-torque arm and attempt to position the scale as perpendicular as possible to the torque arm.
11. Pull on the fish scale while maintaining perpendicularity to the mini-torque arm until the spring-scale reads 7lbs.
12. Record the resulting linear thrust value on the point-load cell.
13. Repeat the process for four more trials.

### **Weight Testing:**

Test Duration: 20 minutes

Place: Construction Management Soils Lab

Testing Procedure:

1. Assemble the pruner power system assembly containing all components found in Appendix B1.
2. Place the complete pruner power system assembly on the soils scale.
3. Record the weight value.

### **Cut Cycle Time Testing:**

Test Duration: 2 hours

Place: Hogue Technology Building Machine Shop

Testing Procedure:

1. Get a branch from a fruit-bearing tree with a diameter ranging from 7/8" to 1". Make sure there is enough length to make three cuts.
2. Position the cutting blade in the fully open position.
3. Place the branch for the first cut on the anvil.
4. Start the stopwatch while simultaneously starting the branch cut. Complete the cut and return to the open position. When the blade returns to the fully open position, stop the stopwatch.
5. Record the cutting cycle time.
6. Repeat the procedure for 2 more 7/8" to 1" diameter branch cuts.

**Maximum Branch Cut Testing:**

Test Duration: 20 minutes

Place: Hogue Technology Building Machine Shop

Testing Procedure:

1. Obtain a branch from a fruit-bearing tree which approximately has a 1.50" diameter
2. Place the open pruner blade and anvil around the 1.50 inch diameter branch.
3. Attempt to cut the branch.
4. Record the success of the cut as PASS/FAIL.

**Branch Cut Rate Testing:**

Test Duration: 2 hours

Place: Hogue Technology Building Machine Shop

Testing Procedure:

1. Obtain 3 branches from a fruit-bearing tree which have a diameter ranging from 7/8" to 1". Make sure each branch has a sufficient length for 10 consecutive cuts.
2. With the pruner blade open, start the stopwatch as the operator begins the 1<sup>st</sup> of 10 consecutive cuts.
3. Stop the watch, after the operator has completed 10 consecutive cuts on the branch.
4. Record the time on engineering paper.
5. Repeat the process for the other two branches.

Safety Note: If a team member is holding the branch, ensure their fingers are ALWAYS clear of the blade and anvil.

**Deliverables:**

### Parameter Values:

Below the values for the “parameters of interest” are explained:

**Weight:** The total weight of the power system components was recorded to be **5.87 lbs.** This satisfies the weight requirement limit of 6 lbs.

**Battery Life:** It is required that the pruner power system supplies cutting force for 1,000 cuts. The battery life of the Makita 5 Ah battery depleted approximately 25% after 213 cuts of branch diameters ranging from 0.3” to 1”. From this, we can determine that the battery would last roughly **862** cuts. This is not satisfactory with regard to the design requirements.

**Max. Branch Cut:** The current power system of the pruner is **unable** to cut a branch with a diameter of 1.50”. This is not satisfactory with regards to the design requirement.

### Calculated Values:

**Branch Cut Rate:** Using the specifications of the ball screw/nut and the Makita XDT08, it is determined that the unit should be able to cut 10 7/8” to 1” diameter branches in **52.7 seconds.**

**Cutting Cycle Time:** Using the equations and method explained in the “predicted performance” section of the testing report, it is determined that the cutting cycle time while operating at 1000 RPM should be **1.67 seconds.**

**Thrust Output:** Using the Machinery’s Handbook equation for the Ball screw driving torque, it is predicted that (in the test) a 7 lb. force on the torque arm should result in an approximately 111 lb thrust. This equation is explained in the “predicted performance” section of the testing report.

### Conclusion:

From the five testing procedures for the power system of the pruner it can be determined that the cut cycle time, branch cutting rate, weight, and ball screw thrust output are satisfactory with regard to the power system’s design requirements. However, the power system is unable to withstand the stresses experienced during a 1.50” diameter branch cut and the battery is approximately 140 short of satisfying the battery life requirement.



## Report Appendix:

McMaster-Carr Ball Screw		Brushless Motor	
Model #	6641K3	Operating RPM	800
Diameter (in)	0.625		
Lead (mm/rev)	n/a	Linear Speed (in/s)	
Lead (in/rev)	0.203	2.71	
Required Stroke Length (in)	Length to Complete Cycle (in)	Load of Max. Cut (lb)	
2.23	4.46	750	
	Description	Diameter (in.)	Lead (in/rev)
Ball Screw	Ball screw w/ One Machined End	.625 in	13/64"
Ball Nut	Round Ball Nut	1.3125 in. (OD)	13/64'
Required Torque For Load (lb*in)		Cycle Time (s)	
26.94		1.647	
Shear Stress on Hex Adapter (lb/in^2)			
8781.169249			

10 Cuts (Diameter: 7/8" - 1")	
Trial	Time (s)
1	52.36
2	54.21
3	44.65
Average Time (s)	
50.41	

## Appendix J – Resume

### THOMAS WILSON

1901 N. Walnut St. #88 ■ Ellensburg, WA 98926  
Phone: (360)-520-3807 ■ Email: thomastylerswilson@gmail.com

*Senior level student of Mechanical Engineering Technology seeking internship or career to gain knowledge, experience, and merit in the field.*

**GPA: 3.0**

#### **Key skills and knowledge areas:**

- Knowledge of the processes involved in various aspects of Engineering. Strong command of AutoCAD, SolidWorks, and MS Office.
- Excellent shop and safety skills honed from work as a technician and warehouse worker. Able to diagnose and solve problems within a system or a piece of equipment. Knowledge of basic shop and machining tools.
- Strong team collaboration skills. Able to work with team members to achieve goals. Able to effectively communicate in a workplace.

#### **EDUCATION**

**Central Washington University – Ellensburg, WA**

Bachelor of Science in Mechanical Engineering Technology (BSMET), **Graduation: June 2016**

**Centralia Community College – Centralia, WA**

Associates of Applied Science in Energy Technology/Power Operations (AAS) **Graduation: June 2013**

**Napavine High School – Napavine, WA**

High School Diploma **Graduation: June 2011**

#### **TECHNICAL SKILLS**

- **Programs:** AutoCAD, MS Office, Rhino, Solidworks
- **Machining:** Milling machines, lathes, band saws, grinders, drill presses, chop saws, taps, and micrometers
- **Shop:** Basic tool knowledge, hand grinders, bolt kits, battery systems, electrical motor systems, water pump systems, electrical vacuum systems, wiring

#### **WORK EXPERIENCE**

- **Technician:** 1/2014 - 1/2015

*Hired by N.W. Scrubbers and Sweepers as a technician to refurbish and service equipment.*

- **Security and Maintenance Officer:** 5/2012- 9/2012

*Hired by Tacoma Power to maintain and patrol the Mossyrock Park Campground.*

- **Forklift Operator:** 9/2012 - 1/2013

*Hired by Fred Meyer Distribution Center as forklift operator and shipping specialist. Employee of the Month (November 2012)*

- **Shift Manager (Fast Food):** 8/2010 – 9/2013

*Hired by Jack in the Box restaurant, promoted to shift manager.*

#### **Clubs**

- **Electric Vehicle Club, C.W.U.**  
*President, Central Washington University*
- **American Society of Mechanical Engineers (ASME) Club**  
*Member, Central Washington University*
- **American Foundry Society (AFS)**  
*Member, Central Washington University*

## **Appendix K – References**

Material Property Data - MatWeb – Material Database - <http://www.matweb.com/>

Carbon Fiber Tube Data – Rockwest Composites -  
<http://www.rockwestcomposites.com/browse/round-carbon-fiber-tubing>

Machine Elements in Mechanical Design – 5<sup>th</sup> Edition – Robert L. Mott

Stress Concentration Factors – Efatigue.com

## **Appendix L – Acknowledgements**

Neil Hauff – Expertise with stress/failure analysis and mechanical design. Neil provided us with the opportunity to gain engineering merit with the pruner project. Neil provides much support through consultation, teaching, and funding.

Dr. Craig Johnson – Expertise with stress and failure analysis

Professor Charles Pringle – Expertise with proposal requirements, design parameters, and failure analysis

Matt Burvee – Assistance with access to Hogue Technology Building machine shop and expertise with manufacturing/testing technology

Professor Greg Lyman – Assistance with purchasing and constructing components for pruner trigger circuit

Professor Christopher Hobbs – Assistance with construction of trigger circuit

Daniel Gibson – Assistance with Dassault Solidworks software and stress/failure analysis

Erich Heilman – Assistance with stress/failure analysis and proposal formatting

Professor Daryl Fuhrman – Assistance with static analysis of load situations

Professor Tedman Bramble – Expertise with machine shop technology